# PREDICTING LOSSES IN GRAIN SORGHUM [SORGHUM BICOLOR (L.) MOENCH] CAUSED BY FREEZES DURING GRAINFILL

by

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# CHAPTER 1

## PREDICTING SEED DRY MATTER ACCUMULATION IN GRAIN SORGHUM FOR ESTIMATING YIELD LOSSES FROM FREEZE

### 1.1 Abstract

Modelers and crop yield forecasters would like to better predict and comprehend the impacts of natural agronomic disasters such as early fall freezes on grain sorghum [Sorghum bicolor(L.) Moench]. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] in 1986 and 1987 and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] in 1987. Percent of maximum seed weight was calculated with treatment variables of bloom date, hybrid, and location-year and regressed on growing degree-days(GDD) from anthesis with base temperatures (Tb) of 1.0 and 5.7 C. Three commercial hybrids ranging in maturity were used: Asgrow 'Dorado E'(early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity). Cumulative GDD accounted for 97 to 99% of the variability in percent maximum seed weight for each hybrid. Hybrids differed 10% or more between 200 to 500 GDD according to individual regression equations, but the equation combined over hybrids was within 6% of the individual equations.

Combined over all hybrids and location-years: Percent maximum seed wt.= $-43.0 + 0.276GDD - 0.0001332GDD^2$ for Tb of 1.0 C. This regression accounted for 95% of the variability in seed weight and predicted maximum seed weight at 1040 GDD. Tb of 5.7 C gave nearly identical results and did not improve precision of prediction. It appears that this equation can be used to determine percent yield loss state-wide.

## 1.2 Introduction

Annual sorghum [Sorghum bicolor (L.) Moench] acreages in excess of four million (Farm Facts, 1987), exemplifies the success that sorghum has in Kansas. This success has led to an ever increasing number of acres vulnerable to freeze because of late planting and other factors which cause variability in stage of maturity in the fall. Early fall freezes in 1984 and 1985 reduced sorghum yields. Yield reductions were substantial, yet the exact impact was not known.

Many components are involved in determining final yield of a crop including many environmental factors which create difficulty in predicting yields. In grain sorghum, the influence of temperature and water stress on key physiological and developmental processes have been shown to have the greatest relative importance (Eastin, 1976; Lewis et al., 1974; and Nix and Fitzpatrick, 1969). Thus, a thermal component, growing degree-days (GDD), often has been used as a quantitative expressor for a concept introduced more than two centuries ago (Wang,1960). Using the GDD concept, (Schaffer, 1980) found that regardless of planting date all hybrids basically require the same number of GDD's during the grain filling period.

Yield components (number of heads per acre, seed number

per head, and seed weight) are factors in yield, but tend to compensate for each other, so that any one component is too inconsistent to serve as a reliable yield predictor (Vanderlip,1979). It has been reported that events in GS2 (panicle initiation to bloom) are important for potential number of seed, while those in GS3 (bloom to physiological maturity) directly affect seed size (Eastin and Sullivan, 1974). Though seed number is more important than seed weight (Saeed et al., 1986), seed weight is the only component left to be determined during grainfill. Seed weight becomes more critical to yield as high temperature stress increases (Saeed et al., 1986). Therefore, final dry weight per kernal is the only component of yield which can change after kernal number has been set (Kiniry, 1988).

Kernels of sorghum do not fill at a constant rate from anthesis to maturity (Kersting et al.,1961). A sorghum kernel exhibits an initial lag period followed by a relatively long period of near linear growth and finally a second lag period just before maturity. Thus, a kernel obtains 90 % of its volume and 10-15 % of its dry weight during the non-linear growth period (Gerik et al.,1987). Kernel dry matter accumulation is similar in wheat (_Triticum aestivum_ L.) (Sofield et al., 1977), oats (_Avena sativa_ L.) (McKee et al., 1979), and corn (_Zea mays_ L.) (Johnson and Tanner,1972). At the soft dough stage, approximately half the grain dry weight is accumulated. At the hard dough

stage, three-fourths of the grain dry weight has accumulated, and if frozen will produce light, chaffy grain (Vanderlip, 1979). Other studies have been conducted to determine yield loss at various stages of growth from yield limiting conditions. Larson and Maranville (1977) showed reductions of 30% from stalk breakage occurring at the early dough growth stage.

Many kernel dry matter accumulation curves have been based upon days from flowering to physiological maturity, for example in corn (Johnson and Tanner, 1972), oats (McKee et al., 1979), and sorghum (Kersting et al., 1961; Collier, 1963; and Pauli et al., 1964). A cumulative growing degree-day (GDD) method may be a more reliable estimator for grain dry matter accumulation than calendar days.

Thus, the objective of this study was to develop a model using GDD after anthesis to estimate seed dry matter accumulation and predict yield losses one can expect from freeze occurring before maturity. For simplicity, if one component of yield and one environmental factor could predict yield loss with some precision over a variety of blooming dates, hybrids, and locations, this could prove to be helpful.

## 1.3 Materials and Methods

Field experiments were conducted in 1986 and 1987 at the Kansas State Univ. Research Farm at Manhattan and in 1987 the Fort Hays Branch Exp. Station at Hays. Three commercial hybrids were used: Asgrow 'Dorado E' (early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity).

Experiments were planted 3 June 1986 and 2 June 1987 at Manhattan and 9 June 1987 at Hays. A randomized complete block design was used with one replication at Manhattan in 1986 and three replications in 1987 at Manhattan and Hays. Individual plots were 45 m in length with 4 rows spaced 76 cm apart at Manhattan in 1986, and 26 m in length with 10 rows in 1987. Plots were 27 m in length with 12 rows spaced 90 cm apart at Hays in 1987. Plant populations were approximately 111,200 plants hectare$^{-1}$ at Manhattan in 1986 and 1987, and 86,000 plants hectare$^{-1}$ at Hays. The soil was a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] both years at Manhattan and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] at Hays. Plots were fertilized according to the Kansas State University Soil Testing Lab recommendations. At Manhattan, Furadan at the rate of 1.1 a.i. kg ha$^{-1}$ was furrow applied at planting time. A tank mix of 2.2 a.i. kg

alachlor $ha^{-1}$ and 1.1 a.i. kg atrazine $ha^{-1}$ was applied directly after planting for grass and broadleaf weed control. Seed was treated with Screen$^{R}$ safener. Proprazine at a rate of 2.5 a.i. kg $ha^{-1}$ was applied pre-plant at Hays. Weed control was supplemented by hand hoeing later during the growing season.

To measure seed growth, panicles were tagged in groups of 150 to 200 when they had bloomed half-way down the panicle. A colored tag was then placed around the peduncle just above the flag leaf. After two to three days, another group was tagged with a different color and possibly a third group was tagged with yet another color to signify the various anthesis dates. Beginning approximately two weeks after anthesis in 1986 (one week in 1987), 5 to 15 panicles per anthesis date for each hybrid were taken twice weekly (approximately 3 to 4 day intervals) and placed immediately into a forced air oven at Manhattan and drying room at Hays. Drying temperatures were 55 to 70 C at Manhattan in 1986 and 52 C in 1987. At Hays, samples were dried at 35 to 38 C for approximately two weeks. Panicles were hand cut approximately 15 cm below the base to ensure easy handling during threshing. Several harvests were obtained after black layer (Eastin et al.,1973) occurred at the base of the panicle, until the supply of panicles were exhausted, to ensure that accurate final seed weight was obtained. When a group of samples had dried, panicles were threshed with a

single head thresher with minimum draft to minimize loss of minute seeds from panicles harvested early in the grain fill period. Grain was carefully cleaned by a blower and by hand. Seed counts of 200 were made from a random bulk sample and dried at 70 C for two to three days to determine kernel dry weight.

Growing dereee-days (GDD) with base temperatures (Tb) of 1.0 C (Schaffer, 1980) and 5.7 C (Donatelli, 1988 unpublished) were calculated from daily maximum (Tmax) and daily minimum (Tmin) temperatures by Eq. [1]

$$GDD = \frac{Tmax + Tmin}{2} - Tb \qquad [1]$$

with Tmax not to exceed 38 C. GDD accumulation began the day after anthesis.

Climatic data were obtained from the Physics Dept. of Kansas State Univ. through weather stations located approximately 2 km from the Manhattan plots and 1 km from the Hays plots.

Due to variations in seed weight (Table 1.1) among bloom dates, hybrids, and the three location-year (loc-yr) combinations which occurred, it was decided to convert seed weight to a percent of maximum. Percent maximum seed weight was regressed on linear, quadratic, and cubic functions of GDD. Regressions were run using covariates of bloom date, hybrid, and location-year.

## 1.4 Results and Discussion

Analysis began by testing for differences in percent maximum seed weight among bloom dates, across hybrids within a particular loc-yr. Bloom dates were highly significant for Manhattan-1987 and Hays-1987, but non-significant for Manhattan-1986. Ideal weather at Manhattan in 1986 created non-stressful, homogenous conditions which may explain the non-significance for bloom dates and hybrids. Ninety-seven percent of the variability in seed weight was accounted for by GDD's for Manhattan-1986 and 99% at Manhattan and Hays in 1987. The linear and quadratic terms accounted for the majority of the sums of squares. Sampling began one week later in 1986 at Manhattan and may explain the non-significance of the cubic term. Standard error (SE) ranged from 5.0 for Manhattan-1986 to 2.6 for Manhattan-1987. Coefficient of variation (CV) ranged from 6.2 for Manhattan-1986 to 3.4 for Manhattan-1987 with Tb of 1.0 C (Table 1.3).

Bloom dates were then combined within hybrids to test for differences in percent maximum seed weight among hybrids for a loc-yr. The results closely paralleled the previous analysis with significant differences among hybrids occurring for Manhattan-1987 and Hays-1987. Little variation in the SE, r-square, or CV occurred.

When hybrids were tested across locations, 98% of the

variability was accounted for with a SE of 3.9 and CV of 5. Nearly all variables and interactions (tests for differences in slope) including hybrids were significant with little variation between Tb's throughout the analysis. Hybrids were then combined and comparisons made among loc-yr combinations. The only noticable changes occurred with an increase in SE to 5.0 for Tb of 1.0 C and 5.2 for Tb of 5.7 C (Tables 1.3 and 1.4).

An analysis was then run using a cubic function of GDD. This yielded, for Tb of 1.0 C, a SE of 6.4 and a CV of 8.4 with 95% of the variability accounted for. Results from an analysis of a quadratic function were nearly identical to the cubic, contrary to an analysis of only the linear function which yielded a SE of 12.5, CV of 17, and only 81% of the variability accounted for with Tb of 1.0 C (Table 1.3). Tb of 5.7 gave similar results (Table 1.4). It appeared that increase in precision from using the Tb of 5.7 was negligible. Some precision was lost by pooling bloom dates, hybrids, and loc-yr's into combined regressions Eq.[2] and Eq.[3]

$$\%\ \text{max. seed wt.} = -43.0 + 0.276\text{GDD} - 0.0001332\text{GDD}^2 \quad [2]$$

$$= -46.0 + 0.3585\text{GDD} - 0.000220\text{GDD}^2 \quad [3]$$

for Tb of 1.0 C and 5.7 C, respectively. The negative intercepts are because little data was collected before 200

GDD. Inaccurate predictions of percent maximum seed weight would occur below 200 GDD. Figures 1.1 and 1.2 show percent maximum seed weight vs. GDD. Apparently, seed weight accumulates more in the first half of development [about 60% (Fig. 1.1)] than second half. Yield loss prediction on a percentage basis would merely be percent maximum seed weight achieved subtracted from 100 percent. The combined regression estimated maximum seed weight to occur at 1040 GDD with Tb of 1.0 C and 810 GDD for Tb of 5.7 C.

Variability in the prediction of percent maximum seed weight among hybrids and the combined equation can be seen in Fig. 1.3 and 1.4. Hybrids differed by 10 % or more between 200 to 500 GDD with Tb of 1.0 C. The combined equation was within 6% of individual hybrids. Differences were much the same among loc-yr's (Fig. 1.5 and 1.6). Number of samples taken after physiological maturity varied and may have influenced regressions since significant differences appeared in the analysis for most variables, though the contribution to the total sums of squares often was small.

Use of a cubic term in the combined equation may have illustrated a more true accumulation curve, yet increased precision would have been small. After reaching a maximum, seed weight has been known to decrease. Thus the downward direction of the latter part of the curve, may be natural

because of weight loss attributed to respiration (Kersting et al., 1961 and Eastin et al., 1973).

Percent maximum seed weight was best described by a quadratic polynomial of GDD after anthesis (Fig. 1.1 and 1.2). Cumulative GDD accounted for 95 to 96% of the variability in percent maximum seed weight across bloom dates, hybrids, and location-years using either a base temperature (Tb) of 1.0 and 5.7 C. As data were grouped into a combined analysis, it was necessary to sacrifice precision to formulate one equation for use across the state (Tables 1.3 and 1.4). Tb of 1.0 and 5.7 C were nearly identical in precision for prediction of percent maximum seed weight throughout this analysis.

As observed in Table 1.1, seed weight differed greatly for various bloom dates, hybrids, and locations thus illustrating the effect various environmental conditions had on seed weight alone, and necessitating the use of percent maximum seed weight. The early hybrid consistently had lower seed weights and the medium hybrid the highest in both years and locations. Poor seed set at Hays with the medium and late hybrids resulted in rather high seed weights.

The number of GDD (Table 1.2) required to reach maximum seed weight (estimated from regression equations) varied somewhat for hybrids and location-year combinations. GDD maxima for hybrids found using Tb of 1.0 C were:

early--1010; medium--1100; and late--1070 GDD. Manhattan-1986 reached maximum at 970; Manhattan-1987 at 1020; and Hays-1987 at 1140. This shows some discrepancy with the postulation that duration is constant across hybrids and locations (Schaffer, 1980). Over-inflated GDD requirements to reach maximum seed weight at Hays in comparison to Manhattan may be attributed in part to the lack of harvests taken after physiological maturity for the medium and late hybrids at Hays.

## 4.5 Summary and Conclusions

Percent maximum seed dry matter accumulation for grain sorghum was described best by a quadratic polynomial of GDD accumulated after anthesis. A combined analysis accounted for 95% of the variability and yielded the equation: Percent maximum seed wt. = $-43.0 + 0.276\text{GDD} - 0.0001332\text{GDD}^2$ for Tb of 1.0 C. Tb of 5.7 C gave nearly identical results and failed to show any better precision or prediction.

The medium and late hybrids required more GDD to reach maximum seed weight. The cooler temperatures at Hays also trended toward higher GDD requirements. Early senescence of the medium and late hybrids compounded with the fewer harvests taken after physiological maturity may explain higher GDD at Hays.

Many times, covariates of bloom date, hybrid, and location-year were highly significant although their contribution to the total sums of squares was small.

Predictions of percent maximum seed weight differed by as much as 10% among hybrids, however, with the combined analysis only 6% error in the predictions of percent maximum seed weight occurred. Seed weight accumulates more rapidly in the first half of development than the second.

Over a range of environmental conditions and three hybrids, GDD after anthesis accounted for 95% of the

variation in seed dry matter accumulation. Though some precision was sacrificed, the results appear to be acceptable for calculating percent maximum seed weight to estimate yield loss.

Table 1.1. Final seed weights for bloom dates, hybrids, and location-years.

| Hybrid | Bloom date | Manhattan-1986 | Manhattan-1987 | Hays-1987 |
|---|---|---|---|---|
| | | g/1000 | | |
| Early | 1 | 20.46 | 20.06 | 21.43 |
| Early | 2 | 23.30 | 23.29 | 23.86 |
| Early | 3 | 22.75 | 22.03 | 26.41 |
| Medium | 1 | 23.50 | 27.76 | 35.57 |
| Medium | 2 | 25.79 | 29.50 | 34.39 |
| Medium | 3 | 25.59 | --- | 33.81 |
| Late | 1 | 23.71 | 26.13 | 32.37 |
| Late | 2 | 24.88 | 27.52 | 31.21 |
| Late | 3 | 26.74 | --- | 29.75 |

Table 1.2. Predicted number of growing degree-days(GDD) required for maximum seed weight for hybrids and loc-yrs for two base temperatures.

| Hybrid | GDD required | Loc-yr | GDD required |
|---|---|---|---|
| Base 1.0 C | | | |
| Early | 1010 | Manhattan-1986 | 970 |
| Medium | 1100 | Manhattan-1987 | 1020 |
| Late | 1070 | Hays-1987 | 1140 |
| Combined | | | 1040 |
| Base 5.7 C | | | |
| Early | 800 | Manhattan-1986 | 780 |
| Medium | 860 | Manhattan-1987 | 810 |
| Late | 820 | Hays-1987 | 880 |
| Combined | | | 810 |

Table 1.3. R-square, standard error, and coefficient of variation values from analyses for variables including covariates at Tb of 1.0 C.

| Covariate included | statistic | Location-year Manhattan 1986 | Manhattan 1987 | Hays 1987 | Combined |
|---|---|---|---|---|---|
| Bloom date | $R^2$ | 0.97 | 0.99 | 0.99 | --- |
| | SE | 5.0 | 2.6 | 2.8 | --- |
| | CV | 6.2 | 3.4 | 3.9 | --- |
| Hybrid | $R^2$ | 0.95 | 0.99 | 0.99 | --- |
| | SE | 5.3 | 2.6 | 3.4 | --- |
| | CV | 6.5 | 3.6 | 4.8 | --- |
| Hybrid | $R^2$ | --- | --- | --- | 0.98 |
| | SE | --- | --- | --- | 3.9 |
| | CV | --- | --- | --- | 5.1 |
| Loc-year | $R^2$ | --- | --- | --- | 0.97 |
| | SE | --- | --- | --- | 5.0 |
| | CV | --- | --- | --- | 6.5 |
| None (Cubic GDD) | $R^2$ | | | | 0.95 |
| | SE | | | | 6.4 |
| | CV | | | | 8.4 |
| (Quadratic GDD) | $R^2$ | | | | 0.95 |
| | SE | | | | 6.4 |
| | CV | | | | 8.4 |
| (Linear GDD) | $R^2$ | | | | 0.81 |
| | SE | | | | 12.5 |
| | CV | | | | 16.5 |

Table 1.4. R-square, standard error, and coefficient of variation values from analyses of given variables including covariates for Tb of 5.7 C.

| | | Location-year | | | |
|---|---|---|---|---|---|
| Covariate included | statistic | Manhattan 1986 | Manhattan 1987 | Hays 1987 | Combined |
| Bloom date | $R^2$ | 0.97 | 0.99 | 0.99 | --- |
| | SE | 5.2 | 2.7 | 2.6 | --- |
| | CV | 6.4 | 3.4 | 3.7 | --- |
| Hybrid | $R^2$ | 0.94 | 0.99 | 0.99 | --- |
| | SE | 6.0 | 2.9 | 3.4 | --- |
| | CV | 7.4 | 3.7 | 4.7 | --- |
| Hybrid | $R^2$ | --- | --- | --- | 0.98 |
| | SE | --- | --- | --- | 4.2 |
| | CV | --- | --- | --- | 5.5 |
| Loc-year | $R^2$ | --- | --- | --- | 0.97 |
| | SE | --- | --- | --- | 5.2 |
| | CV | --- | --- | --- | 6.8 |
| None | | | | | |
| (Cubic GDD) | $R^2$ | | | | 0.96 |
| | SE | | | | 6.0 |
| | CV | | | | 7.9 |
| (Quadratic GDD) | $R^2$ | | | | 0.96 |
| | SE | | | | 6.1 |
| | CV | | | | 8.0 |
| (Linear GDD) | $R^2$ | | | | 0.82 |
| | SE | | | | 4.0 |
| | CV | | | | 150.5 |

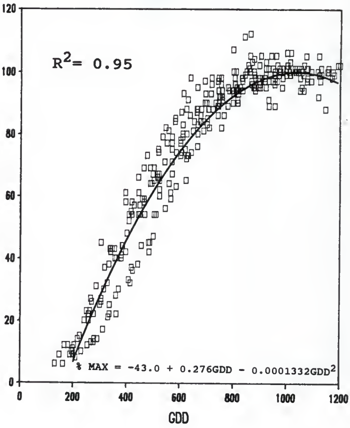


Figure 1.1. Combined regression across bloom dates, hybrids, and location-years of percent maximum seed weight of grain sorghum on GDD after anthesis for base of 1.0 C.

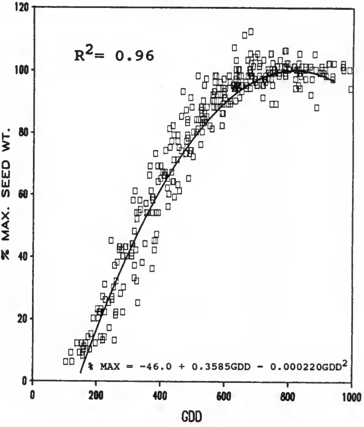


Figure 1.2. Combined regression across bloom dates, hybrids, and location-years of percent maximum seed weight of grain sorghum on GDD after anthesis for base of 5.7 C.

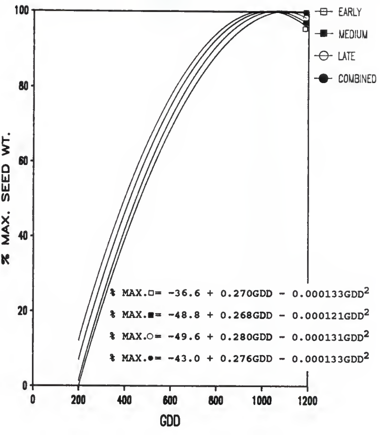


Figure 1.3. Comparison of regressions predicting percent maximum seed weight for individual hybrids and a combined regression for Tb of 1.0 C.

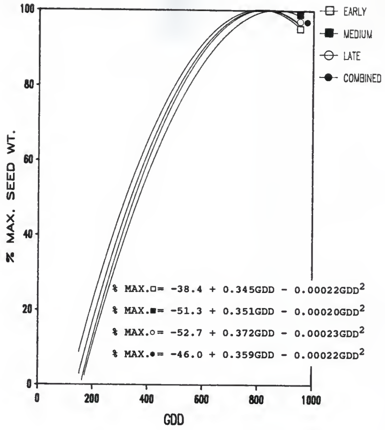


Figure 1.4. Comparison of regressions predicting percent maximum seed weight for individual hybrids and a combined regression for Tb of 5.7 C.

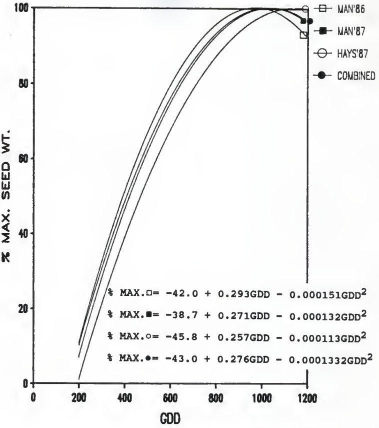


Figure 1.5. Comparison of regressions predicting percent maximum seed weight for individual location-years and a combined regression for Tb of 1.0 C.

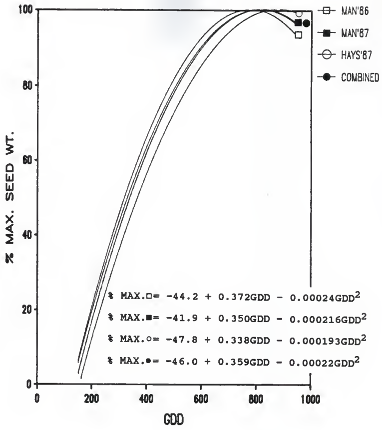


Figure 1.6. Comparison of regressions predicting percent maximum seed weight for individual location-years and a combined regression for Tb of 5.7 C.

CHAPTER 2

# ESTIMATION OF GRAIN SORGHUM TEST WEIGHT CHANGES DURING GRAINFILL

## 2.1. Abstract

The ability to better comprehend the potential impact of early fall freezes on grain sorghum [Sorghum bicolor (L.) Moench], not only on yield, but also reduced test weight would benefit the sorghum producer. Marketing penalties assessed for low test weight grain can be substantial. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] in 1986 and 1987 and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] in 1987. Test weight was measured with variables including bloom date, hybrid, and location-year, and regressed on growing degree-days (GDD) from anthesis with a base temperature of 1.0 C. Three commercial hybrids ranging in maturity were used. Test weight increase was best described by a quadratic polynomial of cumulative GDD, accounting for 86% of the variability in test weight. Coefficients from the equation were used to calculate the maximum test weight of 77.9 kg $hL^{-1}$ at 912 GDD. Individual regression equations with various bloom date, hybrid

combinations estimated maximum test weight to be reached in the range of 750 to 950 GDD. Harvests taken early in the grainfill period produced test weights higher than the rather low test weights generally reported with frozen sorghum. Some question remains whether test weights following an actual freeze would coincide with the findings in this study. It does appear that maximum test weight was reached before maximum seed weight was obtained.

## 2.2. Introduction

Literature dealing specifically with test weights of sorghum [Sorghum bicolor (L.) Moench] is rather scarce. The importance to the sorghum producer though can be substantial. For producers who rely on storage and marketing of sorghum through a local elevator, a penalty often is assessed for low test weight sorghum or grain may be refused totally (Table 2.1). On a larger marketing scale, Table 2.2 shows test weights for U. S. grade requirements for sorghum (Schoeff and Page, 1977).

Adverse weather conditions such as wet, cool conditions, early freeze, or drougthy conditions have been reported to lower test weights in grain sorghum. Early fall freezes in 1984 and 1985 reduced grain sorghum yields in Kansas, and apparently reduced quality as well. Test weights (weight per unit volume) as low as 41 kg $hL^{-1}$ (32 lb $bu^{-1}$) were fairly common due to an early freeze and poor maturing conditions in 1975 in Kansas (Feedstuffs, 1975). Larson and Maranville (1977) showed year to year differences in sorghum test weights due to varying environmental conditions.

Subramanyam et al., (1980) showed test weights to be 67.8 kg $hL^{-1}$ at approximately the soft dough stage, 75.0 kg $hL^{-1}$ at hard dough, and 76.8 kg $hL^{-1}$ at physiological

maturity. A study comparing various desiccation and plant severing treatments on sorghum (Bovey and McCarty, 1965), found substantially reduced test weight when treatments were applied at grain moisture levels of 50% (Table 2.3). Larson and Maranville (1977) showed that stalk breakage near the peduncle node at heading resulted in a final test weight of 68.6 kg $hL^{-1}$, at early dough 69.0 kg $hL^{-1}$, and at hard dough 70.6 kg $hL^{-1}$. Highest yielding treatments had highest test weights and lowest yielding treatments lowest test weights.

Studies dealing with freezing of corn (Carter and Hesterman, 1987) showed test weights to be 64 kg $hL^{-1}$ or less for corn frozen at the dough stage (normal 72 kg $hL^{-1}$). If frost occurred close to half-milk stage, test weights were close to normal. Scott et al. (1957) found that maximum yield and test weight was reached at about the same time for wheat. It was also shown that continued wetting and drying decreased test weight in wheat.

The objective of this study was to measure sorghum test weight increase in relation to cumulative growing degree-days (GDD) after anthesis and to assess the impact on sorghum grain quality as a result of an early fall freeze.

## 1.3 Materials and Methods

Field experiments were conducted in 1986 and 1987 at the Kansas State Univ. Research Farm at Manhattan and the Fort Hays Branch Exp. Station at Hays in 1987. Three commercial hybrids were used: Asgrow 'Dorado E' (early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity).

(For additional information on materials and methods--refer to Chapter 1).

Grain samples were carefully cleaned with a blower and by hand. In 1987, chaff (glumes, rachis, branch fractions, etc.) and seeds with glumes still attached, were removed from samples, manually by sifting lighter materials to the top of a small grain pan with a shaking motion by hand to make samples as homogenous as possible. In 1986, precision in cleaning methods was not as great. Samples varied with the amount of chaff and number of seeds with glumes. Samples were allowed to equilibrate to 10% moisture after cleaning. Samples were then measured for test weight with a Dickey John-GAC II moisture and test weight meter reported in pounds per bushel and converted to kg $hL^{-1}$. For samples that were too small to be measured by the machine, test weights were obtained by standard elevator procedure using a calibrated volume container. Comparisons were made to

ensure similar test weights were measured by both methods.

Growing dereee-days (GDD) base (Tb) of 1.0 C (Schaffer, 1980) were calculated from daily maximum (Tmax) and daily minimum (Tmin) temperature by Eq. [1]

$$GDD = \frac{Tmax + Tmin}{2} - Tb \qquad [1]$$

with Tmax not to exceed 38 C. GDD accumulation began the day after anthesis.

Climatic data were obtained from the Physics Dept. of Kansas State Univ. through weather stations located approximately 2 km from the Manhattan plots and 1 km from the Hays plots.

Test weight was regressed on linear and quadratic functions of GDD (SAS, 1987). Preliminary regressions were run and it was concluded the cubic term was not needed in this analysis. Regressions were run with covariates of bloom date, hybrid, and location-year.

## 2.4. Results and Discussion

Test weight increases in relation to cumulative growing degree-days (GDD) was best described by a quadratic polynomial. A combined regression across bloom dates, hybrids, and location-years (loc-yrs) was run in which cumulative GDD accounted for about 86% of the variability in test weight. The regression estimated a maximum test weight of 77.9 kg $hL^{-1}$ at 912 GDD.

Predicted test weights ranged from 47 kg $hL^{-1}$ (37 lb $bu^{-1}$) at 200 GDD to 80 kg $hL^{-1}$ (62 lb $bu^{-1}$) at approximately 900 GDD for the three loc-yrs (Fig. 2.1, 2.2, and 2.3). Severe shrinkage occurred with seed from the early harvests thus increasing test weights slightly which otherwise may not have occurred if left to dry naturally under field conditions. Test weights were higher than expected between 200 to 300 GDD in reference to test weights reported for sorghum resulting from a freeze in 1975 in Kansas (Feedstuffs, 1975).

Figure 2.1 illustrates the variability that occurred at Manhattan in 1986. The first harvests (between 200 to 400 GDD) were dried at high temperatures (65 to 70 C) resulting in excessive cracking during threshing thus creating a higher density pack in the test weight containers and possibly increasing test weights. Variability in test

weights after drying temperatures were reduced to 55 C in 1986 was probably because of chaff (glumes, rachis, branch fractions, etc.) and glumes still attached to the seed which varied among hybrids and sampling dates. A slight occurrance of mold appeared during the latter part of grainfill possibly contributing more variability to the data collected at Manhattan in 1986.

Bloom dates were tested by regression analysis for differences in test weights across hybrids in a particular loc-yr. Covariates of bloom date or hybrids were non-significant. For Manhattan-1986, all variables in the regression equation accounted for only 67% of the variability. Linear and quadratic GDD terms were highly significant (Table 2.4 and 2.5). Only 56% of the variability in test weight was accounted for with Manhattan-1986 when bloom dates were grouped and hybrid effects were tested (Table 2.5).

In 1987, 93 to 97% of the variability in test weight at Manhattan and Hays was accounted for with GDD, probably due to the increased precision in cleaning methods as well as more acceptable drying temperatures (Table 2.4). Manhattan-1987 showed no significant main effect differences among bloom dates or hybrids, but did show significant interactions with GDD. Hays-1987 showed significant main effect differences among bloom dates and hybrids as well as significant interactions with GDD.

An analysis was then conducted as though nine different hybrids were being tested by treating the hybrids from each loc-yr as different hybrids. Eighty-seven percent of the total variability was accounted for and showed significant differences for all variables including hybrids (Table 2.6).

Hybrids were then combined across loc-yrs with 81% of the total variability accounted for and no significant differences among hybrids (Table 2.6). When hybrids were grouped to test for differences among loc-yrs, 84% of the variability was accounted for, but significant differences among loc-yrs existed. Slightly wetter conditions and traces of mold occurring on the grain later during grainfill for Manhattan-1987 may also have contributed to this.

Regressions were then run for all bloom date and hybrid combinations (Table 2.7) to ascertain the number of GDD required to reach maximum test weights. Several of the bloom date and hybrid combinations for Manhattan-1986 were deleted because less than 50% of the variability in test weight was accounted for. GDD required to reach maximum test weight varied from approximately 750 to 950. Maximum test weights (calculated from the regressions) for various bloom date-hybrid combinations ranged from 74 to 80 kg $hL^{-1}$. Maximum test weight appeared to be reached around 830 GDD which yielded a combined maximum test weight of 75.0 kg $hL^{-1}$ for Manhattan-1986. Manhattan-1987 bloom date-hybrid combinations had much higher r-square values with 907 GDD

required to reach the maximum test weight of 78.2 kg $hL^{-1}$. Hays-1987 was similar to Manhattan-1987 with a large proportion of the variability accounted for with 913 GDD needed to reach the maximum test weight of 77.9 kg $hL^{-1}$.

Table 2.8 shows test weight increases for individual hybrids at each loc-yr at 100 GDD increments. With harvests beginning approximately 200 GDD after anthesis, the hybrids varied in test weight from 42 kg $hL^{-1}$ for the late maturity hybrid at Hays-1987 to 57.4 kg $hL^{-1}$ for the late maturity hybrid at Manhattan-1986. R-squares (Table 2.8) were low for Manhattan-1986 in comparison to the other two loc-yrs.

Finally, a combined regression was run across bloom dates, hybrids, and loc-yrs which accounted for 86% of the variablility in test weight. Maximum test weight of 77.9 kg $hL^{-1}$ was reached at 912 GDD. GDD required to reach maximum appeared a bit high from observing Figures 2.1, 2.2, and 2.3 and was thought to be due to the variability at Manhattan-1986, therefore another regression was run for Manhattan-1987 and Hays-1987 only. This yielded a slightly higher r-square of 0.90 with maximum test weight of 78.2 kg $hL^{-1}$ at 918 GDD, thus very similar to using all data.

The freeze of 1975 in Kansas produced test weights that were often 45 kg $hL^{-1}$ (Feedstuffs, 1975). This would have necessitated a freeze occurring very early during grainfill (200 to 300 GDD) to coincide with results in this study. As mentioned earlier, seeds shrunk substantially, possibly

uncharacteristically of those left under field conditions to dry. Thus more seed could fit into a given volume, increasing test weight measurements. Another possible explanation for lower test weights reported for frozen sorghum could be due to increased chaff with the grain or glumes attached to seeds which would lower test weight.

It does appear from this study that test weight reaches maximum at 800 to 900 GDD as opposed to maximum seed weight which was reached at 1040 GDD (Chapter 1).

## 2.5. Summary and Conclusions

The pattern of test weight increase in grain sorghum was best described by a quadratic polynomial. A combined regression across bloom dates, hybrids, and location-years accounted for 86 % of the total variability in test weight. Maximum test weight appeared to be reached before physiological maturity when maximum seed weight has been attained (Eastin et al., 1973). Higher than expected test weight measurements were obtained for the early harvests during grainfill.

Individual regressions for various bloom date, hybrid combinations yielded maximum test weights ranging from 74 to 80 kg $hL^{-1}$ reached between 750 and 950 GDD. Studies conducted on seed dry matter accumulation using these same experimental materials showed maximum seed weight to be reached at just over 1000 GDD. A combined regression showed maximum test weight was reached at approximately 900 GDD. Thus, it appears that maximum test weight was reached before maximum seed weight.

Literature describing the 1975 early freeze in Kansas, gave indications of low test weights that coincide with those from the first harvests taken in this study. Substantial seed shrinkage may have inflated test weights associated with the early portion of grainfill in this

study. In order to have obtained such low test weights later in the grain fill period, it would have required substantial weathering of the grain or excessive chaff and a large number of glumes attached to seeds. Thus a direct effect of freezing, may be lower threshing ability of the grain which has been a common belief among many sorghum producers. Questions still remain as to the exact reason low tests weights seem to be so prevalent in frozen sorghum.

Table 2.1. Penalties in cents per hundred weight for low test weight grain sorghum in pounds per bushel and kilograms per hectoliter at the Farmers Cooperative-Manhattan,KS 1988.

| Test Weight | | Penalty |
|---|---|---|
| lb $bu^{-1}$ | kg $hL^{-1}$ | cents $cwt^{-1}$ |
| > 56 | > 72.1 | .00 |
| 55.9 - 55.0 | 72.0 - 70.9 | .01 |
| 54.9 - 54.0 | 70.8 - 69.6 | .02 |
| 53.9 - 53.0 | 69.5 - 68.3 | .03 |
| 52.9 - 52.0 | 68.2 - 67.0 | .04 |
| 51.9 - 51.0 | 66.9 - 65.7 | .06 |
| 50.9 - 50.0 | 65.6 - 64.4 | .09 |
| 49.9 - 49.0 | 64.3 - 63.1 | .12 |
| 48.9 - 48.0 | 63.0 - 61.8 | .15 |
| 47.9 - 47.0 | 61.7 - 60.6 | .19 |
| 46.9 - 46.0 | 60.5 - 59.3 | .23 |
| 45.9 - 45.0 | 59.2 - 58.0 | .27 |
| < 45 | < 58 | not accepted |

Table 2.2. Test weight requirements for grain sorghum Grades.

| Grade U. S. | Minimum test weight | |
|---|---|---|
| | $lb\ bu^{-1}$ | $kg\ hL^{-1}$ |
| 1 | 57 | 73.4 |
| 2 | 55 | 70.9 |
| 3 | 53 | 68.3 |
| 4 | 51 | 65.7 |

* Obtained from Kansas State Coop. Extension Service. L-58. August 1977.

Table 2.3. Test weights for grain sorghum head cut at various moisture percents (Bovey and McCarty, 1965).

| Variety | Moisture | Year 1961 | 1962 |
|---|---|---|---|
| | % | kg $hL^{-1}$ | kg $hL^{-1}$ |
| Martin | 48 | 64.4 | 49.0 |
| | 38 | 79.9 | 72.1 |
| | 26 | 76.0 | 76.0 |
| Combine Kafir-60 | 50 | 67.0 | 46.4 |
| | 38 | 73.4 | 68.3 |
| | 32 | -- | 73.4 |

Table 2.4. Significance levels and associated r-square values obtained from Type III sums of squares for analysis of covariance including bloom date.

| Variable | Manhattan-1986 | Manhattan-1987 | Hays-1987 |
|---|---|---|---|
| Bloom | | | ** |
| GDD | ** | ** | ** |
| $GDD^2$ | ** | ** | ** |
| GDD*Bloom | | ** | |
| $GDD^2$*Bloom | | * | ** |
| $R^2$ | 0.67** | 0.94** | 0.97** |

*,**. Significant at the 0.05 and 0.01 probability level, respectively.

Table 2.5. Significance levels and associated r-square values obtained from Type III sums of squares for analysis of covariance including hybrid.

| Variable | Manhattan-1986 | Manhattan-1987 | Hays-1987 |
|---|---|---|---|
| Hybrid | | | ** |
| GDD | ** | ** | ** |
| $GDD^2$ | ** | ** | ** |
| GDD*Hybrid | | ** | |
| $GDD^2$*Hybrid | | | ** |
| $R^2$ | 0.56** | 0.93** | 0.97** |

*,**. Significant at the 0.05 and 0.01 probability level, respectively.

Table 2.6. Significance levels and associated r-square values obtained from Type III sums of squares for analysis of covariance including hybrid and loc-year.

| Treated as 9 hybrids | | Across Hybrids | | Across Loc-yrs | |
|---|---|---|---|---|---|
| Hybrid[1] | ** | Loc-yr | * | Hybrid | |
| GDD | ** | GDD | ** | GDD | ** |
| $GDD^2$ | ** | GDD2 | ** | GDD2 | ** |
| GDD*Hybrid | ** | GDD*Loc-yr | ** | GDD*Hybrid | |
| $GDD^2$*Hybrid | * | GDD2*Loc-yr | | GDD2*Hybrid | |
| $R^2$ | 0.87** | | 0.84** | | 0.81** |

*,**. Siginificant at the 0.05 and 0.01 probability level, respectively.

[1]Three hybrids X three locations.

Table 2.7. Bloom date and hybrid combinations with required GDD to reach maximum test weight and associated maximum test weights calculated from regressions.

| Hybrid | Bloom | Manhattan-1986 | | Manhattan-1987 | | Hays-1987 | |
|---|---|---|---|---|---|---|---|
| | | GDD | MAX.TEST | GDD | MAX.TEST | GDD | MAX.TEST |
| | | | $kg\ hL^{-1}$ | | $kg\ hL^{-1}$ | | $kg\ hL^{-1}$ |
| Early | 1 | -- | -- | 874 | 76.2 | 921 | 80.2 |
| Early | 2 | -- | -- | 817 | 77.0 | 902 | 79.7 |
| Early | 3 | 717 | 75.9 | 751 | 76.2 | 906 | 79.9 |
| Medium | 1 | -- | -- | 891 | 78.9 | 942 | 77.2 |
| Medium | 2 | 835 | 75.6 | 944 | 79.1 | 937 | 77.3 |
| Medium | 3 | 754 | 75.9 | -- | -- | 878 | 77.4 |
| Late | 1 | 923 | 74.6 | 960 | 79.5 | 888 | 77.6 |
| Late | 2 | -- | -- | 901 | 79.2 | 804 | 78.0 |
| Late | 3 | 771 | 76.4 | -- | -- | 800 | 77.4 |
| Combined | | 827 | 75.0 | 907 | 78.2 | 913 | 77.9 |

Table 2.8. Test weight increase by hybrid for three location-years measured in 100 GDD increments.

| | Manhattan-1986 maturity | | | Manhattan-1987 maturity | | | Hays-1987 maturity | | |
|---|---|---|---|---|---|---|---|---|---|
| GDD | Early | Medium | Late | Early | Medium | Late | Early | Medium | Late |
| | $kg\ hL^{-1}$ | | | | | | | | |
| 200 | 55.0 | 49.1 | 57.4 | 52.4 | 52.4 | 53.7 | 49.4 | 48.8 | 42.0 |
| 300 | 60.5 | 57.2 | 62.6 | 59.4 | 59.3 | 60.2 | 57.3 | 56.1 | 52.2 |
| 400 | 65.0 | 63.9 | 66.9 | 65.2 | 65.1 | 65.7 | 64.0 | 62.2 | 60.8 |
| 500 | 68.6 | 69.1 | 70.3 | 69.8 | 70.0 | 70.3 | 69.6 | 67.4 | 67.6 |
| 600 | 71.2 | 72.8 | 72.8 | 73.2 | 73.9 | 74.0 | 73.9 | 71.4 | 72.7 |
| 700 | 73.0 | 75.0 | 74.4 | 75.4 | 76.7 | 76.8 | 77.1 | 74.4 | 76.1 |
| 800 | 73.8 | 75.7 | 75.1 | 76.4 | 78.6 | 78.6 | 79.1 | 76.3 | 77.7 |
| 900 | 73.7 | 74.9 | 74.8 | 76.3 | 79.5 | 79.4 | 79.8 | 77.2 | 77.7 |
| 1000 | 72.7 | 72.6 | 73.7 | 74.9 | 79.3 | 79.3 | 79.4 | 77.0 | 75.9 |
| $R^2$ | .41 | .61 | .50 | .94 | .92 | .90 | .94 | .97 | .98 |

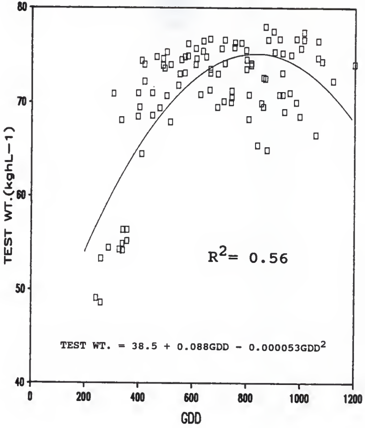


Figure 2.1. Test weight vs. growing degree-days (GDD) for Manhattan, 1986.

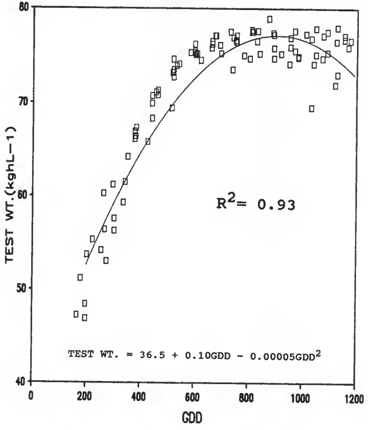


Figure 2.2. Test weight vs. growing degree-days (GDD) for Manhattan, 1987.

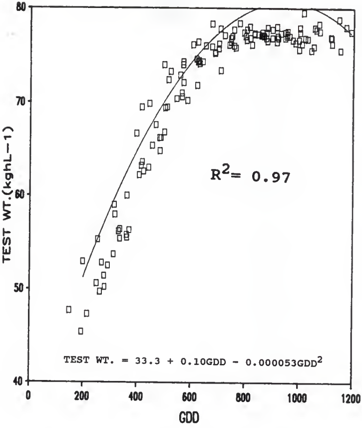


Figure 2.3. Test weight vs. growing degree-days (GDD) for Hays, 1987.

CHAPTER 3

# COMPARISON OF DESICCATION vs. HEAD CUT METHODS TO SIMULATE FREEZING IN GRAIN SORGHUM

## 3.1 Abstract

The methods used to develop growth curves in estimating yield and quality losses of a crop from agronomic disasters can be very important. This study evaluated the effects of foliar application of paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) at weekly intervals following anthesis to simulate effects of freezing on seed weight and test weight of grain sorghum [Sorghum bicolor (L.) Moench]. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] at Manhattan and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] at Hays in 1987. Percent maximum seed weight and test weight were regressed with the variables hybrid, and location, and growing degree-days (GDD) from anthesis with a base temperature of 1.0 C. Three commercial hybrids ranging in maturity were used. Cumulative GDD accounted for 93% of the total variability from desiccated rows of sorghum in predicting percent maximum seed weight. A quadratic polynomial best described

this relationship and yielded this equation: Percent max. seed wt.= $5.0 + 0.1741GDD - 0.0000797GDD^2$. Cumulative GDD accounted for 83% of the total variability for test weight increase which also was described best with a quadratic equation. The desiccation method gave much higher percent maximum seed weights and test weights especially in the early phase of grainfill (200 to 500 GDD) than the head cut method. Apparently, translocation of materials from the culm contributed to these increased seed weights and test weights. As much as a 20 to 30% difference in maximum seed weight occurred between the two methods for percent maximum seed weight. A 10 to 15 kg $hL^{-1}$ difference occurred in test weight estimation during the 200 to 300 GDD interval.

## 3.2 Introduction

Seed dry matter accumulation curves have been developed for many crops through laborious and time consuming effort. These curves are excellent for understanding the pattern of dry matter accumulation in the seed, but their application for predicting the effects from agronomic disasters such as an early freeze is questionable due to the methods used to collect the data. Under circumstances where a freeze has occurred, the physiological functions in the plant can play an improtant role in terms of translocation of materials to or from the seed. Efforts to simulate freezes through desiccation of the crop canopy have been limited. Much of the work on desiccation of grain sorghum [Sorghum bicolor (L.) Moench] involved finding methods to hasten moisture loss in the grain by killing the canopy to promote earlier harvesting and reduce losses from pests and weathering.

The non-grain parts of cereal crops are known to lose weight during grainfill. This often has been interpreted as a transfer of materials assimilated prior to grainfill to the grain. It has been shown in sorghum that during grain formation culms lose dry weight. This loss indicates a translocation of material out of culms into developing grain (Jacques et al., 1975). At the soft dough stage, the culm is losing weight (Vanderlip, 1979), and at the hard dough

stage, the culm is at its lowest weight. The culm can contribute as much as 10% to the final weight of the grain.

Other work, with corn (Zea mays L.), showed that following a frost in late August, grain yield of corn had doubled by early October (Daynard et al., 1969). This suggests that assimilate stored in the stalks prior to grainfill may have contributed to grain yield. Experiments conducted to simulate frost damage in corn using the herbicide paraquat sprayed on leaves [(Brown,unpublished data) as cited by Hume and Campbell,1972], showed grain yield continued to increase following desiccation, again indicating stored assimilates were translocated to the grain. Redistribution of assimilates from stalks to ears, even with complete leaf death, increased kernel dry weight beyond the weight on the freeze date and reduced yield loss (Afuakwa and Crookston, 1984). Corn frozen at the milk stage will produce very chaffy grain and low test weight, probably less than 64 kg $hl^{-1}$ (normal is 72 kg $hl^{-1}$). With freezes even at the half-milk stage, test weights would be close to normal (Carter and Hesterman, 1987). Bauer et al., (1986) suggest that in wheat, some grain dry matter accumulation also occurs after windrowing, before complete desiccation of vegetative tissue.

Using various methods to reduce grain moisture in grain sorghum, Bovey and McCarty (1965) reported greatest reductions in grain yields and test weight when grain

moisture was above 40 to 50% at the start of the treatments. A severing treatment was significantly different from other treatments used and produced the lowest seed weight. Test weight, like seed weight, was reduced when a desiccant was applied at the higher grain moisture levels. Severing at the head had the greatest seed weight and test weight reduction followed by severing at the soil, defoliation, and application of DNBP or magnesium chlorate. Clegg et al., (1969) showed a 23% yield loss from desiccating at 42% grain moisture with Diquat (9,10-dehydro-8a, 10a-diazoniaphenanthrene-2A).

The objective of this study was to determine if differences occur in seed weight and test weight accumulation curves using paraquat as a desiccant vs. head cutting.

3.3 Materials and methods

Field experiments were conducted in 1987 at the Kansas State Univ. Research Farm at Manhattan and the Fort Hays Branch Exp. Station at Hays. Three commercial hybrids were used: Asgrow 'Dorado E' (early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity).

Experiments were planted 2 June 1987 at Manhattan and 9 June 1987 at Hays. A split plot design was used with three replications at Manhattan and Hays. Individual plots were 26 m in length with 10 rows spaced 76 cm apart at Manhattan. Plots were 27 m in length with 12 rows spaced 90 cm apart at Hays. Plant populations were approximately 111,200 plants $ha^{-1}$ at Manhattan and 86,000 plants $ha^{-1}$ at Hays. The soil was a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] at Manhattan and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope) at Hays. Plots were fertilized according to the Kansas State University Soil Testing Lab recommendations. At Manhattan, Furadan at the rate of 1.1 a.i. kg $ha^{-1}$ was furrow applied at planting time. A tank mix of 2.2 a.i. kg alachlor $ha^{-1}$ and 1.1 a.i. kg atrazine $ha^{-1}$ was applied directly after planting for grass and broadleaf control. Seed was treated with Screen$^{R}$ safener. Propazine at a rate of 2.2 a.i. kg

$ha^{-1}$ was applied pre-plant at Hays. Weed control was supplemented by hand hoeing later during the growing season.

Approximately one week after one-half of the panicles were at some stage of bloom in a plot, paraquat (1,1'-dimethyl 1-4,4'-bipyridinium ion) was applied on a single row 4.5 to 6 m in length at Manhattan and 3.5 m at Hays. Paraquat at a rate of 1.12 a.i. kg $ha^{-1}$ was mixed in water at a spray volume of 188 liters $ha^{-1}$ at 1.5 kg $cm^{-2}$. A surfactant was added at 0.5% of the spray mixture. A hand sprayer was used with a tee-jet nozzle and application was made below the panicle at Manhattan with one application on each side of the row. At Hays, a 3.5 m plexiglass box was used to concentrate the single application made above the panicles. Desiccation treatments were continued at weekly intervals till physiological maturity. Desiccated rows were separated by border rows. Applications were made during the mornings to minimize possible wind drift. Noticable leaf discoloration was visible towards afternoon and leaf senescence was at or near 100 percent after several days. For details concerning the head cut procedure, refer to Chapter 1.

Panicles were allowed to dry under field conditions for at least two weeks after desiccation and as long as five weeks, depending upon the drying conditions. Thirty heads were then harvested and stored indoors till threshing. At Hays the entire 3.5 m length of row was harvested and stored

indoors. Threshing was done with an Almaco plot thresher. The blower on the thresher was almost closed for the early desiccations to ensure little loss of minute seeds. Samples were carefully cleaned with a blower and by hand. Two hundred seeds were counted from a random bulk sample and dried at 70 C for 2 to 3 days to determine seed weight. Test weight measurements for both head cut and desiccation methods and methods for calculating GDD and sources of weather data are described in Chapter 2.

Seed weights were converted to a percent of maximum seed weight as in Chapter 1. Percent maximum seed weight and test weight were regressed on linear and quadratic functions of GDD (SAS, 1987). Regressions were run with covariates of bloom date, hybrid, and location-year.

## 3.4 Results and discussion

A quadratic polynomial best described the relationship between cumulative GDD and percent maximum seed weight for the desiccation method. Cumulative GDD accounted for 93% of the variability over all desiccations yielding the equation: Percent max. seed wt. = $5.0 + 0.1741\text{GDD} - 0.0000797\text{GDD}^2$. Cumulative GDD accounted for 83% of the variability in test weight over all desiccations.

The desiccation method gave higher percent maximum seed weights and test weights compared to the head cut method (Fig. 3.1 and 3.3), especially during early grainfill between 200 to 500 GDD. This agrees with Bovey and McCarty (1965) that severing treatments gave smaller seed weights and test weights than defoliation or desiccation. At 200 GDD, the head cut method showed 7% of maximum seed weight while the desiccation method resulted in 37%. At 300 GDD, the difference between methods was 22% (Fig. 3.1). At 600 GDD, there was only a 6% difference between the predicted seed weights and at 800 GDD, the methods were nearly identical. Early in grainfill, as much as a 20 to 30% contribution was made through translocation. This compares to other reports on sorghum of 10% (Vanderlip, 1979) and corn of nearly 50% (Daynard et al., 1969).

Table 3.1 shows the GDD required to reach maximum seed

weight predicted from the regression of the desiccation and head cut methods. The desiccation method required 1090 GDD to reach maximum seed weight whereas the head cut method required approximately 1040 GDD. The Manhattan site required 1070 GDD while Hays required 1120 GDD (Figure 3.2). The high GDD requirements may be because no desiccations occurred after physiological maturity. The late hybrid at Hays had a GDD requirement of 933 which may have been because of early leaf senescence. Also, the last desiccation had a lower percent maximum seed weight than the control which may have forced the quadratic to peak prematurely. Since desiccations were only made on weekly intervals rather than sampled twice weekly as with the head cut method, this could explain some of the added variability. Estimated maximum seed weights (Table 3.1) for the desiccation method did not differ much in comparison to maximum seed weights obtained from the head cut method (Chapter 1).

The Manhattan site was expected to have higher percent maximum seed weight at least during early grainfill due to alteration in procedure for application of the desiccant. Panicles were not sprayed at Manhattan, while at Hays, application was made above the panicle. Fischer et al., (1976) reported that after anthesis, photosynthesis by the panicle was 17 percent of the total photosynthesis for the plant. Thus higher percent maximum seed weights were

expected at Manhattan due to photosynthesis by the panicle. This did not appear to be the case.

When hybrids were tested for differences in estimation of percent maximum seed weight at Manhattan, 98% (Table 3.2) of the variability was accounted for through cumulative GDD with no significant differences among hybrids. Hybrids were significantly different at the .05 level at Hays with 96% of the total variability being accounted for. The significant differences may be due, again, to the lack of harvests taken near and after physiological maturity at Hays, as well as early leaf senescence of the medium and late hybrids.

When locations were tested for differences in estimation of percent maximum seed weight, 95% of the variability was accounted for by a quadratic GDD equation with no significant differences (Table 3.4 ). Locations were then combined and the desiccation and head cut methods were tested for differences. Significant differences occurred at the .05 level (Table 3.4 ) with 95% of the variability accounted for with cumulative GDD using a quadratic polynomial. Most of this difference occurred within the early phase of grainfill apparently when translocation of materials from the culm occurred (Jacques et al, 1975 and Vanderlip, 1979) and corn (Daynard et al., 1969 and Afuakwa and Crookston, 1984). It is doubtful whether any significant amount of photosynthesis occurred in the leaves the day desiccation applications were made.

Paraquat applications were made in the morning hours and definite leaf discoloration and wrinkling occurred the first day.

Test weight varied between the two methods with maxima reached at 77.7 kg $hL^{-1}$ for the head cut method and 76.4 kg $hL^{-1}$ with the desiccation method. The head cut method estimated test weight to be 50.7 kg $hL^{-1}$ at 200 GDD compared to 64.6 kg $hL^{-1}$ for the desiccation. GDD required to reach maximum test weight were 910 for head cut and 1050 for the desiccation. Again, the medium and late hybrids had fewer harvests and early leaf senescence that occurred prematurely from low soil moisture conditions caused an apparent over-estimation of the GDD required to reach maximum test weight. A maximum test weight of 76.7 kg $hL^{-1}$ required 1150 GDD at Hays. Manhattan reached a maximum test weight of 76.2 kg $hL^{-1}$ at 1000 GDD. At 1000 GDD for Hays, test weight was already 76.4 kg $hL^{-1}$, thus the additional 150 GDD made little difference.

When hybrids were tested for differences in test weight, significant differences occurred at Manhattan but not at Hays with 96 to 98% of the total variability accounted for (Table 3.3). When hybrids were combined to test for location differences in test weight, 86% of the total variablility was accounted for by cumulative GDD using a quadratic polynomial with no apparent location differences. When the two methods (desiccation and head

cut) were tested, differences were found between methods in estimating test weights. Desiccation gave higher test weights which agrees with previous work (Bovey and McCarty, 1965). Differences in GDD when maximum test weight was reached for the two locations may be a result, again, of early leaf senescence at Hays.

It is not known how closely the application of paraquat as a desiccant simulates a total leaf kill which may occur from an actual freeze. But in reference to previous literature concerning translocation from the culm to the grain, it is felt that desiccation more closely simulates freezing as opposed to the head cut method at least in the early phase of grainfill. Test weights were much higher than expected from the desiccation method. As stated in Chapter 2, test weights were higher than expected for the head cut method particularly during early grainfill. This was thought to be due to excessive shrinking of seed since the panicles were not allowed to dry under field conditions. The desiccation method though, gave yet higher test weights. Excess chaff in the grain because of poor threshing as a result of freeze could be a possible explanation for occurrences of low test weights that seem so prevalent with frozen sorghum (Feedstuffs, 1975). These results point more to the threshing problems with frozen sorghum. In this study, samples were meticulously cleaned of all chaff and glume-attached seed.

Results for the desiccation method did not illustrate as well the findings in Chapter 2 (head cut method) that maximum test weight was reached before maximum seed weight. But once again, fewer harvests were taken for the desiccation method near and after physiological maturity which may explain the variability observed.

## 3.5 Summary and conclusions

Large differences occurred between the desiccation and head cut methods for estimation of percent maximum seed weight and test weight, especially for the early phase of grainfill. A quadratic polynomial of growing degree-days (GDD) accounted for 93% of the variability in percent maximum seed weight and 83% of the variability in test weight for the desiccation method.

There were no significant differences among hybrids or locations in estimation of percent maximum seed weight. When methods (desiccation and head cut) were tested, significant differences did occur. When hybrids and locations were tested for differences in test weight accumulation, only hybrid differences were found at Manhattan. Differences in methods were also found for test weight accumulation with the desiccation method giving higher measurements especially in early grainfill.

Translocation of materials from the culm, as cited in the literature, appears to be the best explanation for the increased seed weight percentages and test weight for the desiccation method over the head cut method early in grainfill. According to the regression analysis, as much as 20 to 30% of the total seed weight was being contributed from the culm when plants were desiccated between 200 to 300

GDD after anthesis. Thus it would appear that the accumulation curves developed with the desiccation method better simulates conditions of an actual freeze. Yield losses would not be as severe as portrayed by the head cut growth curves. No definite explanation has been found for the lower test weights that generally occur in years of a freeze other than excess chaff in the grain.

Table 3.1. Number of growing degree-days (GDD) required to reach maximum seed weights and estimated maximum seed weights for Manhattan and Hays.

| Location | Hybrid | Required GDD | Est. Max. Seed Wt. |
|---|---|---|---|
| | | | g/1000 |
| Manhattan | Early | 1043 | 23.49 |
| Manhattan | Medium | 1152 | 29.58 |
| Manhattan | Late | 1051 | 26.88 |
| Hays | Early | 1223 | 25.20 |
| Hays | Medium | 1100 | 31.29 |
| Hays | Late | 933 | 28.51 |

Table 3.2. Significance levels for individual regression coefficients for hybrids and associated covariates for percent maximum seed weight at Manhattan and Hays.

| | Location | |
|---|---|---|
| Variables | Manhatttan | Hays |
| Hybrid | | * |
| GDD | ** | ** |
| $GDD^2$ | ** | ** |
| GDD*Hybrid | | |
| $GDD^2$*Hybrid | | |
| $R^2$ | 0.98 | 0.96 |
| CV | 4.0 | 6.8 |

*,**. Significant at the .05 and .01 probability levels, respectively.

Table 3.3. Significance levels for individual regression coefficients for hybrid and associated covariates for test weight at Manhattan and Hays.

| Variables | Location | |
|---|---|---|
| | Manhattan | Hays |
| Hybrid | ** | |
| GDD | ** | ** |
| $GDD^2$ | ** | ** |
| GDD*Hybrid | * | ** |
| $GDD^2$*Hybrid | | |
| $R^2$ | 0.98 | 0.96 |
| CV | 1.0 | 1.5 |

*,**. Significant at the .05 and .01 probability levels, respectively.

Table 3.4. Significance levels for individual regression coefficents for location and associated covariates for percent maximum seed weight and test weight.

| Variables | % Max. seed wt. | Test wt. |
|---|---|---|
| Location | | |
| GDD | ** | ** |
| $GDD^2$ | ** | ** |
| GDD*Location | | |
| $GDD^2$*Location | | |
| $R^2$ | 0.95 | 0.86 |
| CV | 6.2 | 2.3 |

*,**. Significant at the .05 and .01 probability levels, respectively.

Table 3.5. Significance levels for individual regression coefficients for the desiccation method and associated covariates of percent maximum seed weight and test weight.

| Variables | % Max. seed wt. | Test wt. |
|---|---|---|
| Method | * | * |
| GDD | ** | ** |
| $GDD^2$ | ** | ** |
| GDD*Method | ** | ** |
| $GDD^2$*Method | ** | ** |
| $R^2$ | 0.96 | 0.91 |
| CV | 7.7 | 3.4 |

*,**. Significant at the .05 and .01 probability levels, respectively.

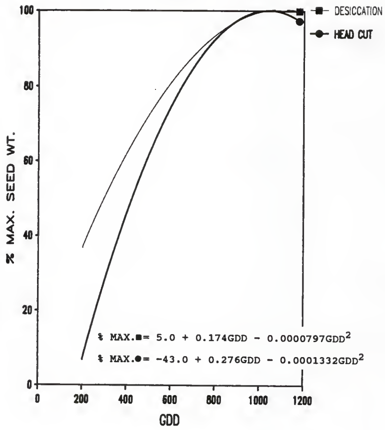


Figure 3.1. Percent maximum seed weight vs. growing degree-days (GDD) of desiccation and head cut methods predicted from regression analysis.

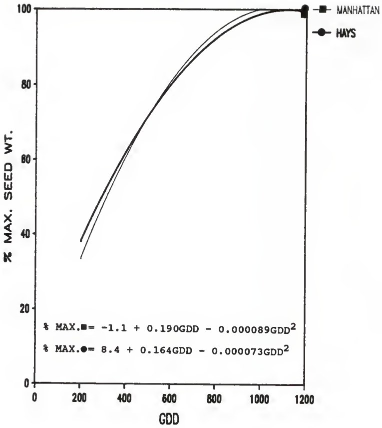


Figure 3.2. Percent maximum seed weight vs. growing degree-days (GDD) for Manhattan and Hays predicted from regression analysis.

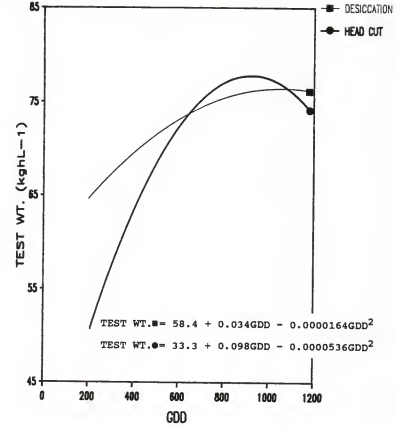


Figure 3.3. Test weight vs. growing degree-days (GDD) for desiccation and head cut methods predicted from regression analysis.

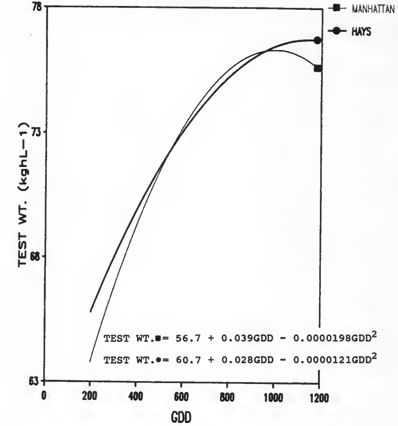


Figure 3.4. Test weight vs. growing degree-days (GDD) for Manhattan and Hays predicted from regression analysis.

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# APPENDIX A

# SUPPLEMENTARY TABLES AND FIGURES

Table A.1. Significance levels obtained from Type III sum of squares for analysis of covariance including bloom date at Tb of 1.0 C.

| | LOCATION-YEAR | | |
|---|---|---|---|
| Variables | Manhattan-1986 | Manhattan-1987 | Hays-1987 |
| Bloom date | | ** | ** |
| GDD | ** | ** | ** |
| $GDD^2$ | ** | ** | ** |
| $GDD^3$ | | * | ** |
| GDD*Bloom date | * | * | ** |
| $GDD^2$*Bloom date | | * | ** |
| $GDD^3$*Bloom date | | | ** |
| $R^2$ | 0.97** | 0.99** | 0.99** |

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.2. Significance levels obtained from Type III sums of squares for analysis of covariance including hybrid at Tb of 1.0 C.

| | LOCATION-YEAR | | |
|---|---|---|---|
| Variables | Manhattan-1986 | Manhattan-1987 | Hays-1987 |
| Hybrid | | ** | ** |
| GDD | ** | ** | ** |
| $GDD^2$ | ** | ** | ** |
| $GDD^3$ | | * | ** |
| GDD*Hybrid | * | * | ** |
| $GDD^2$*Hyrid | | | ** |
| $GDD^3$*Hybrid | | | ** |
| $R^2$ | 0.95** | 0.99** | 0.99** |

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.3. Significance levels obtained from Type III sums of squares for analysis of covariance including location-year at Tb of 5.7 C.

| | LOCATION-YEAR | | |
|---|---|---|---|
| Variables | Manhattan-1986 | Manhattan-1987 | Hays-1987 |
| Bloom date | | ** | ** |
| GDD | ** | ** | ** |
| $GDD^2$ | ** | ** | ** |
| $GDD^3$ | | | ** |
| GDD*Bloom date | ** | | ** |
| $GDD^2$*Bloom date | | * | ** |
| $GDD^3$*Bloom date | | * | ** |
| $R^2$ | 0.97** | 0.99** | 0.99** |

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.4. Significance levels obtained from Type III sums of squares for analysis of covariance including location-year at Tb of 5.7 C.

| | LOCATION-YEAR | | |
|---|---|---|---|
| Variables | Manhattan-1986 | Manhattan-1987 | Hays-1987 |
| Hybrid | | ** | ** |
| GDD | ** | ** | ** |
| $GDD^2$ | ** | ** | ** |
| $GDD^3$ | | * | ** |
| GDD*Hybrid | ** | * | ** |
| $GDD^2$*Hybrid | | | ** |
| $GDD^3$*Hybrid | * | | ** |
| $R^2$ | 0.94** | 0.99** | 0.99** |

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.5. Significance levels obtained from Type III sums of squares for analysis of covariance at Tb of 1.0 C when analyzed across loc-yr and when hybrids were combined.

| Variables | Across loc-yr | Variables | Hybrids combined |
|---|---|---|---|
| Hybrid | ** | Loc-yr | ** |
| GDD | ** | GDD | ** |
| $GDD^2$ | ** | $GDD^2$ | ** |
| $GDD^3$ | ** | $GDD^3$ | |
| GDD*Hybrid | ** | GDD*Loc-yr | ** |
| $GDD^2$*Hybrid | ** | $GDD^2$*Loc-yr | ** |
| $GDD^3$*Hybrid | ** | $GDD^3$*Loc-yr | ** |
| $R^2$ | 0.98** | $R^2$ | 0.97** |

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.6. Significance levels obtained from Type III sums of squares for analysis of covariance at 5.7 C when analyzed across loc-yr and when hybrids were combined.

| Variables | Across Loc-yr | Variables | Hybrids Combined |
|---|---|---|---|
| Hybrid | ** | Loc-yr | ** |
| GDD | ** | GDD | ** |
| $GDD^2$ | ** | $GDD^2$ | ** |
| $GDD^3$ | ** | $GDD^3$ | * |
| GDD*Hybrid | ** | GDD*Loc-yr | ** |
| $GDD^2$*Hybrid | ** | $GDD^2$*Loc-yr | |
| $GDD^3$*Hybrid | ** | $GDD^3$*Loc-yr | ** |
| $R^2$ | 0.98** | $R^2$ | 0.97** |

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.7. Percent of maximum seed weights calculated from regressions with various increments of growing degree-days of hybrids and location-years and Tb of 1.0 and 5.7 C.

| | Hybrid | | | | Loc-yr | | |
|---|---|---|---|---|---|---|---|
| GDD | Early | Medium | Late | Combined | MAN'86 | MAN'87 | HAY'87 |
| Base 1.0 | | | | | | | |
| 200 | 12.0 | 0 | 1.1 | 6.9 | 10.5 | 10.2 | 1.0 |
| 300 | 32.3 | 20.8 | 22.6 | 27.8 | 32.2 | 30.6 | 21.1 |
| 400 | 49.9 | 39.2 | 41.4 | 46.1 | 51.0 | 48.4 | 38.8 |
| 500 | 64.9 | 55.1 | 57.6 | 61.7 | 66.7 | 63.6 | 54.3 |
| 600 | 77.3 | 68.6 | 71.2 | 74.7 | 79.3 | 76.2 | 67.6 |
| 700 | 86.9 | 79.8 | 82.2 | 85.0 | 89.0 | 86.1 | 78.5 |
| 800 | 93.9 | 88.4 | 90.5 | 92.6 | 95.6 | 93.3 | 87.3 |
| 900 | 98.3 | 94.7 | 96.3 | 97.5 | 99.3 | 97.9 | 93.7 |
| 1000 | 99.9 | 98.6 | 99.38 | 99.8 | 100.0 | 99.9 | 97.9 |
| Base 5.7 C | | | | | | | |
| 200 | 22.0 | 10.7 | 12.7 | 16.9 | 20.6 | 19.5 | 12.0 |
| 300 | 45.8 | 35.6 | 38.6 | 41.7 | 45.8 | 43.7 | 36.2 |
| 400 | 65.2 | 56.4 | 59.9 | 62.2 | 66.2 | 63.6 | 56.4 |
| 500 | 80.3 | 73.2 | 76.7 | 78.2 | 81.8 | 79.2 | 72.9 |
| 600 | 91.2 | 85.9 | 89.0 | 89.9 | 92.6 | 90.4 | 85.4 |
| 700 | 97.8 | 94.6 | 96.7 | 97.1 | 98.7 | 97.4 | 94.1 |
| 800 | 100.0 | 99.2 | 99.9 | 100.0 | 100.0 | 100.0 | 98.9 |

Table A.8. Dates of anthesis for three location-years and dates for black layer at base of panicle in Julian days.

| Location-year | Hybrid | Anthesis date | Black layer |
|---|---|---|---|
| Manhattan-1986 | 1 | 203 | 251 |
| | | 205 | 254 |
| | | 208 | 254 |
| | 2 | 208 | 254 |
| | | 210 | 254 |
| | | 211 | 258 |
| | 3 | 210 | 258 |
| | | 212 | 261 |
| | | 215 | 264 |
| Manhattan-1987 | 1 | 206 | 246 |
| | | 209 | 251 |
| | | 212 | 256 |
| | 2 | 214 | 266 |
| | | 217 | 271 |
| | 3 | 217 | 268 |
| | | 220 | 274 |
| Hays-1987 | 1 | 213 | 258 |
| | | 215 | 261 |
| | | 217 | 265 |
| | 2 | 225 | 275 |
| | | 228 | 279 |
| | | 231 | 282 |
| | 3 | 230 | 279 |
| | | 233 | 286 |
| | | 236 | 289 |

* Daily notes taken in 1987 thus greater precision in dates.

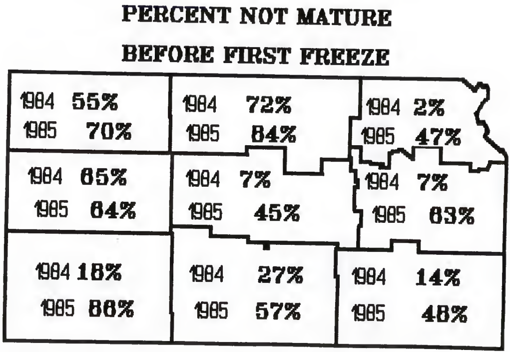


Figure A.1. Percent of acreage not mature before freeze in 1984 and 1985.

AVERAGE DATE OF FIRST 32° FREEZE IN FALL

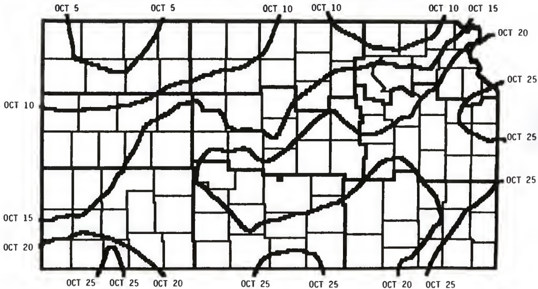


Figure A.2. Average date of first 0 C freeze in the fall.

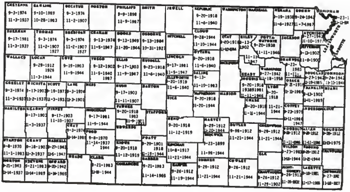

Figure A.3. Range of earliest dates of first 0 C freeze in fall.

# APPENDIX B

## WEATHER DATA

Table B.1. Calendar day, daily maximum temperature, and daily minimum temperature at Manhattan, KS, 1986.

| Julian date | Maximum | Minimum |
|---|---|---|
| | $(C^{o})$ | $(C^{o})$ |
| 120 | 25.41 | 10.78 |
| 121 | 22.09 | 08.42 |
| 122 | 23.06 | 10.25 |
| 123 | 25.36 | 09.50 |
| 124 | 26.81 | 16.50 |
| 125 | 28.55 | 14.51 |
| 126 | 30.15 | 14.88 |
| 127 | 27.47 | 15.35 |
| 128 | 23.26 | 14.51 |
| 129 | 27.64 | 15.26 |
| 130 | 22.62 | 12.40 |
| 131 | 27.14 | 08.78 |
| 132 | 29.79 | 16.50 |
| 133 | 25.46 | 13.05 |
| 134 | 26.26 | 11.87 |
| 135 | 26.81 | 14.05 |
| 136 | 27.98 | 10.05 |
| 137 | 16.93 | 08.46 |
| 138 | 18.70 | 08.78 |
| 139 | 22.09 | 5.181 |
| 140 | 21.75 | 10.21 |
| 141 | 23.51 | 09.38 |
| 142 | 23.02 | 15.09 |
| 143 | 22.72 | 13.30 |
| 144 | 26.59 | 10.90 |
| 145 | 22.18 | 11.54 |
| 146 | 24.48 | 08.46 |
| 147 | 22.82 | 11.62 |
| 148 | 22.67 | 10.53 |
| 149 | 26.86 | 12.97 |
| 150 | 27.81 | 12.72 |
| 151 | 30.27 | 11.83 |
| 152 | 32.22 | 15.47 |
| 153 | 27.42 | 17.06 |
| 154 | 28.61 | 16.50 |
| 155 | 31.20 | 18.56 |
| 156 | 28.38 | 15.86 |
| 157 | 30.09 | 16.76 |
| 158 | 30.76 | 17.81 |
| 159 | 29.25 | 14.84 |

Table B.1., continued.

| Julian date | Maximum | Minimum |
|---|---|---|
| 160 | 29.67 | 17.54 |
| 161 | 31.70 | 15.82 |
| 162 | 26.00 | 14.71 |
| 163 | 31.33 | 10.66 |
| 164 | 32.61 | 13.59 |
| 165 | 30.03 | 18.74 |
| 166 | 33.47 | 15.31 |
| 167 | 34.57 | 20.25 |
| 168 | 34.02 | 21.04 |
| 169 | 33.07 | 21.23 |
| 170 | 33.27 | 20.52 |
| 171 | 33.14 | 22.52 |
| 172 | 32.67 | 22.67 |
| 173 | 30.52 | 19.97 |
| 174 | 31.70 | 16.46 |
| 175 | 29.55 | 17.06 |
| 176 | 33.47 | 17.85 |
| 177 | 34.43 | 22.43 |
| 178 | 33.07 | 21.42 |
| 179 | 34.57 | 17.72 |
| 180 | 36.36 | 19.06 |
| 181 | 28.50 | 16.37 |
| 182 | 29.14 | 18.07 |
| 183 | 32.87 | 14.42 |
| 184 | 33.27 | 19.74 |
| 185 | 34.02 | 23.46 |
| 186 | 34.78 | 24.48 |
| 187 | 25.89 | 17.41 |
| 188 | 30.21 | 18.79 |
| 189 | 34.08 | 22.38 |
| 190 | 30.89 | 22.92 |
| 191 | 30.89 | 18.83 |
| 192 | 31.77 | 17.11 |
| 193 | 31.70 | 18.34 |
| 194 | 31.77 | 18.16 |
| 195 | 34.15 | 23.97 |
| 196 | 34.43 | 23.86 |
| 197 | 34.57 | 23.71 |
| 198 | 34.85 | 24.42 |
| 199 | 36.43 | 24.12 |
| 200 | 34.22 | 23.91 |
| 201 | 30.76 | 17.85 |
| 202 | 29.43 | 14.42 |
| 203 | 31.70 | 19.28 |
| 204 | 34.50 | 20.06 |
| 205 | 38.17 | 24.63 |

Table B.1., continued.

| Julian date | Maximum | Minimum |
|---|---|---|
| 206 | 32.67 | 19.65 |
| 207 | 33.95 | 19.47 |
| 208 | 36.43 | 20.71 |
| 209 | 35.92 | 16.93 |
| 210 | 35.85 | 21.23 |
| 211 | 40.18 | 21.94 |
| 212 | 29.19 | 20.52 |
| 213 | 28.38 | 15.26 |
| 214 | 30.15 | 12.93 |
| 215 | 30.39 | 12.72 |
| 216 | 31.96 | 18.25 |
| 217 | 30.21 | 16.85 |
| 218 | 31.01 | 15.31 |
| 219 | 29.91 | 15.77 |
| 220 | 31.90 | 13.92 |
| 221 | 22.72 | 15.94 |
| 222 | 27.42 | 15.52 |
| 223 | 27.98 | 14.93 |
| 224 | 29.14 | 14.76 |
| 225 | 30.95 | 20.15 |
| 226 | 29.79 | 19.60 |
| 227 | 31.07 | 18.92 |
| 228 | 30.95 | 14.59 |
| 229 | 33.67 | 18.16 |
| 230 | 28.04 | 17.90 |
| 231 | 30.03 | 15.56 |
| 232 | 32.35 | 15.14 |
| 233 | 29.79 | 17.59 |
| 234 | 30.76 | 18.52 |
| 235 | 26.21 | 16.42 |
| 236 | 31.26 | 15.47 |
| 237 | 34.02 | 20.76 |
| 238 | 28.55 | 19.28 |
| 239 | 23.76 | 13.71 |
| 240 | 19.47 | 12.32 |
| 241 | 26.64 | 09.81 |
| 242 | 26.86 | 16.33 |
| 243 | 28.44 | 15.39 |
| 244 | 27.53 | 14.25 |
| 245 | 25.36 | 16.50 |
| 246 | 28.61 | 17.46 |
| 247 | 28.55 | 17.19 |
| 248 | 29.61 | 14.84 |
| 249 | 19.51 | 11.02 |
| 250 | 18.92 | 08.90 |
| 251 | 18.88 | 6.661 |

Table B.1., continued.

| Julian date | Maximum | Minimum |
|---|---|---|
| 252 | 27.92 | 17.90 |
| 253 | 29.85 | 18.34 |
| 254 | 24.32 | 13.42 |
| 255 | 28.84 | 11.22 |
| 256 | 29.49 | 15.26 |
| 257 | 27.42 | 13.84 |
| 258 | 25.36 | 17.72 |
| 259 | 23.81 | 19.24 |
| 260 | 29.67 | 18.07 |
| 261 | 29.43 | 19.42 |
| 262 | 31.20 | 22.92 |
| 263 | 32.09 | 22.33 |
| 264 | 32.15 | 21.85 |
| 265 | 31.58 | 19.28 |
| 266 | 28.32 | 18.92 |
| 267 | 30.76 | 19.92 |
| 268 | 31.14 | 17.19 |
| 269 | 31.45 | 19.97 |
| 270 | 29.67 | 18.12 |
| 271 | 31.58 | 17.81 |
| 272 | 19.15 | 17.28 |
| 273 | 18.25 | 12.77 |
| 274 | 20.62 | 14.51 |
| 275 | 21.56 | 16.20 |
| 276 | 23.91 | 14.76 |
| 277 | 16.89 | 09.38 |
| 278 | 23.97 | 07.99 |
| 279 | 21.61 | 5.725 |
| 280 | 24.78 | 11.06 |
| 281 | 20.57 | 13.47 |
| 282 | 16.16 | 10.17 |
| 283 | 17.72 | 11.10 |
| 284 | 18.43 | 4.096 |
| 285 | 08.42 | 3.054 |
| 286 | 10.90 | 1.670 |
| 287 | 13.59 | 0.864 |
| 288 | 15.52 | 2.746 |
| 289 | 24.02 | 3.247 |
| 290 | 23.97 | 3.749 |
| 291 | 21.94 | 07.40 |
| 292 | 24.48 | 07.60 |
| 293 | 23.31 | 09.54 |
| 294 | 20.01 | 07.87 |
| 295 | 15.52 | 09.22 |
| 296 | 16.93 | 10.94 |
| 297 | 14.42 | 11.54 |

Table B.1., continued.

| Julian date | Maximum | Minimum |
|---|---|---|
| 298 | 12.85 | 10.90 |
| 299 | 13.26 | 5.219 |
| 300 | 23.61 | 3.710 |
| 301 | 23.11 | 10.98 |
| 302 | 18.92 | 5.336 |
| 303 | 20.20 | 3.710 |
| 304 | 22.52 | 07.68 |
| 305 | 07.68 | 0.979 |

Table B.2. Calendar day, daily maximum temperature, daily minimum temperature, and precipitation at Manhattan, Kansas, 1987.

| Julian date | Maximum | Minimum | Precipitation |
|---|---|---|---|
| | ($C^O$) | ($C^O$) | (mm $day^{-1}$) |
| 121 | 31.70 | 12.56 | 0.000 |
| 122 | 27.03 | 16.98 | 1.000 |
| 123 | 26.43 | 16.03 | 1.000 |
| 124 | 18.34 | 13.59 | 37.00 |
| 125 | 15.60 | 12.44 | 07.00 |
| 126 | 23.16 | 11.79 | 5.000 |
| 127 | 24.78 | 10.82 | 2.000 |
| 128 | 29.14 | 09.73 | 0.000 |
| 129 | 28.61 | 12.23 | 0.000 |
| 130 | 30.21 | 16.67 | 0.000 |
| 131 | 30.52 | 18.34 | 0.000 |
| 132 | 29.14 | 16.50 | 0.000 |
| 133 | 31.70 | 14.97 | 0.000 |
| 134 | 29.43 | 16.72 | 3.000 |
| 135 | 29.31 | 13.34 | 0.000 |
| 136 | 30.15 | 11.99 | 0.000 |
| 137 | 31.07 | 18.07 | 0.000 |
| 138 | 30.83 | 19.37 | 4.000 |
| 139 | 33.95 | 19.06 | 0.000 |
| 140 | 28.84 | 18.83 | 0.000 |
| 141 | 22.04 | 12.48 | 25.00 |
| 142 | 22.57 | 9.57 | 0.000 |
| 143 | 19.65 | 08.98 | 0.000 |
| 144 | 25.20 | 16.20 | 14.00 |
| 145 | 27.98 | 16.42 | 0.000 |
| 146 | 28.73 | 17.37 | 08.00 |
| 147 | 20.29 | 16.03 | 48.00 |
| 148 | 26.32 | 15.09 | 1.000 |
| 149 | 24.58 | 16.11 | 0.000 |
| 150 | 30.09 | 16.98 | 0.000 |
| 151 | 31.33 | 16.33 | 0.000 |
| 152 | 29.25 | 18.61 | 0.000 |
| 153 | 25.73 | 14.13 | 1.000 |
| 154 | 25.89 | 09.97 | 0.000 |
| 155 | 29.19 | 09.50 | 0.000 |
| 156 | 30.33 | 14.51 | 0.000 |
| 157 | 30.70 | 15.47 | 0.000 |
| 158 | 33.54 | 18.52 | 0.000 |
| 159 | 32.74 | 20.71 | 0.000 |
| 160 | 31.01 | 21.46 | 0.000 |
| 161 | 24.78 | 20.15 | 1.000 |
| 162 | 32.41 | 21.09 | 0.000 |

Table B.2., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 163 | 34.78 | 22.38 | 0.000 |
| 164 | 37.25 | 22.33 | 0.000 |
| 165 | 39.04 | 19.65 | 0.000 |
| 166 | 38.72 | 20.99 | 12.00 |
| 167 | 35.99 | 21.89 | 0.000 |
| 168 | 34.92 | 21.66 | 0.000 |
| 169 | 33.00 | 20.06 | 09.00 |
| 170 | 32.22 | 18.03 | 0.000 |
| 171 | 31.01 | 20.43 | 0.000 |
| 172 | 34.85 | 19.42 | 0.000 |
| 173 | 34.78 | 19.19 | 08.00 |
| 174 | 32.02 | 17.54 | 0.000 |
| 175 | 32.74 | 17.81 | 6.000 |
| 176 | 28.90 | 17.11 | 1.000 |
| 177 | 29.79 | 14.25 | 0.000 |
| 178 | 30.15 | 15.39 | 0.000 |
| 179 | 33.88 | 17.33 | 23.00 |
| 180 | 27.08 | 19.88 | 0.000 |
| 181 | 22.67 | 16.98 | 1.000 |
| 182 | 30.09 | 13.42 | 0.000 |
| 183 | 32.41 | 16.89 | 0.000 |
| 184 | 30.83 | 18.25 | 0.000 |
| 185 | 30.03 | 19.37 | 0.000 |
| 186 | 31.26 | 19.37 | 2.000 |
| 187 | 35.06 | 20.15 | 0.000 |
| 188 | 32.41 | 19.83 | 09.00 |
| 189 | 32.94 | 23.16 | 3.000 |
| 190 | 32.74 | 23.11 | 0.000 |
| 191 | 34.64 | 23.76 | 0.000 |
| 192 | 33.88 | 23.76 | 0.000 |
| 193 | 26.16 | 17.28 | 15.00 |
| 194 | 25.20 | 12.77 | 0.000 |
| 195 | 29.14 | 10.90 | 0.000 |
| 196 | 34.29 | 16.07 | 0.000 |
| 197 | 35.06 | 19.56 | 0.000 |
| 198 | 30.27 | 22.43 | 1.000 |
| 199 | 34.43 | 22.18 | 1.000 |
| 200 | 35.34 | 24.48 | 0.000 |
| 201 | 35.77 | 23.61 | 0.000 |
| 202 | 35.34 | 21.46 | 0.000 |
| 203 | 34.92 | 21.99 | 0.000 |
| 204 | 36.50 | 22.72 | 0.000 |
| 205 | 38.49 | 23.61 | 0.000 |
| 206 | 38.72 | 24.37 | 0.000 |
| 207 | 38.25 | 23.06 | 0.000 |
| 208 | 37.86 | 23.21 | 0.000 |

Table B.2., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 209 | 38.56 | 23.61 | 0.000 |
| 210 | 38.64 | 23.26 | 0.000 |
| 211 | 39.28 | 24.17 | 0.000 |
| 212 | 39.77 | 23.41 | 0.000 |
| 213 | 41.35 | 25.04 | 0.000 |
| 214 | 41.96 | 26.05 | 0.000 |
| 215 | 39.28 | 22.62 | 08.00 |
| 216 | 31.70 | 19.88 | 1.000 |
| 217 | 33.54 | 16.59 | 0.000 |
| 218 | 36.73 | 19.24 | 5.000 |
| 219 | 36.88 | 20.94 | 0.000 |
| 220 | 30.21 | 20.57 | 0.000 |
| 221 | 30.95 | 18.03 | 0.000 |
| 222 | 32.41 | 15.18 | 0.000 |
| 223 | 37.10 | 16.37 | 0.000 |
| 224 | 26.86 | 21.32 | 30.00 |
| 225 | 28.96 | 21.32 | 0.000 |
| 226 | 34.22 | 20.94 | 0.000 |
| 227 | 36.43 | 24.94 | 0.000 |
| 228 | 34.71 | 18.52 | 0.000 |
| 229 | 33.81 | 15.47 | 0.000 |
| 230 | 30.52 | 18.34 | 6.000 |
| 231 | 33.00 | 18.25 | 0.000 |
| 232 | 36.50 | 19.60 | 0.000 |
| 233 | 38.25 | 25.62 | 0.000 |
| 234 | 27.47 | 15.22 | 0.000 |
| 235 | 25.04 | 14.63 | 0.000 |
| 236 | 17.11 | 15.05 | 2.000 |
| 237 | 34.15 | 16.07 | 29.00 |
| 238 | 21.18 | 15.22 | 18.00 |
| 239 | 22.92 | 13.59 | 1.000 |
| 240 | 28.50 | 10.98 | 0.000 |
| 241 | 28.50 | 15.94 | 0.000 |
| 242 | 25.41 | 14.93 | 0.000 |
| 243 | 26.86 | 12.32 | 0.000 |
| 244 | 30.83 | 11.62 | 0.000 |
| 245 | 29.25 | 14.00 | 0.000 |
| 246 | 31.20 | 16.07 | 0.000 |
| 247 | 33.81 | 17.54 | 0.000 |
| 248 | 32.28 | 19.97 | 0.000 |
| 249 | 21.75 | 18.21 | 5.000 |
| 250 | 28.67 | 16.85 | 1.000 |
| 251 | 26.00 | 13.30 | 0.000 |
| 252 | 29.02 | 10.61 | 11.00 |
| 253 | 25.20 | 14.63 | 0.000 |
| 254 | 27.19 | 13.96 | 0.000 |

Table B.2., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 255 | 23.51 | 11.06 | 0.000 |
| 256 | 30.27 | 11.91 | 0.000 |
| 257 | 33.40 | 19.47 | 0.000 |
| 258 | 28.73 | 17.50 | 12.00 |
| 259 | 24.37 | 16.42 | 0.000 |
| 260 | 24.94 | 15.73 | 0.000 |
| 261 | 25.57 | 13.22 | 1.000 |
| 262 | 24.63 | 10.17 | 0.000 |
| 263 | 24.02 | 07.01 | 0.000 |
| 264 | 21.94 | 08.15 | 0.000 |
| 265 | 23.81 | 07.20 | 0.000 |
| 266 | 29.85 | 07.40 | 0.000 |
| 267 | 32.74 | 12.60 | 0.000 |
| 268 | 29.19 | 12.81 | 0.000 |
| 269 | 31.83 | 15.18 | 0.000 |
| 270 | 31.01 | 17.24 | 0.000 |
| 271 | 25.78 | 12.93 | 0.000 |
| 272 | 22.92 | 08.86 | 0.000 |
| 273 | 26.05 | 6.348 | 0.000 |
| 274 | 31.83 | 08.31 | 0.000 |
| 275 | 19.88 | 2.477 | 0.000 |
| 276 | 21.09 | -01.32 | 0.000 |
| 277 | 28.44 | 07.75 | 0.000 |
| 278 | 21.56 | 10.74 | 0.000 |
| 279 | 20.99 | 4.444 | 0.000 |
| 280 | 17.72 | 3.054 | 0.000 |
| 281 | 23.81 | 4.522 | 0.000 |
| 282 | 16.16 | 5.686 | 0.000 |
| 283 | 6.465 | 2.631 | 0.000 |
| 284 | 14.51 | 0.442 | 0.000 |
| 285 | 23.02 | 1.325 | 0.000 |
| 286 | 24.53 | 2.900 | 0.000 |
| 287 | 25.04 | 10.94 | 3.000 |
| 288 | 17.19 | 11.50 | 11.00 |
| 289 | 15.35 | 5.608 | 19.00 |
| 290 | 21.46 | 1.325 | 0.000 |
| 291 | 21.85 | 5.647 | 0.000 |
| 292 | 11.99 | 2.631 | 0.000 |
| 293 | 10.33 | -02.05 | 0.000 |
| 294 | 12.64 | -04.90 | 0.000 |
| 295 | 19.97 | 6.504 | 0.000 |
| 296 | 14.30 | 4.754 | 0.000 |
| 297 | 13.76 | 1.286 | 0.000 |
| 298 | 10.01 | 0.481 | 14.00 |
| 299 | 17.24 | 3.440 | 0.000 |
| 300 | 15.26 | -0.093 | 0.000 |

Table B.2., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 301 | 22.23 | -02.43 | 0.000 |
| 302 | 26.81 | 07.64 | 0.000 |
| 303 | 28.04 | 07.20 | 0.000 |
| 304 | 17.81 | 14.76 | 47.00 |
| 305 | 23.41 | 13.55 | 0.000 |

Table B.3. Calendar day, daily maximum temperature, daily minimum temperature, and precipitation at Hays, Kansas, 1987.

| Calendar day | Maximum | Minimum | Precipitation |
|---|---|---|---|
| | ($C^o$) | ($C^o$) | (mm $day^{-1}$) |
| 121 | 30.58 | 10.41 | 0.000 |
| 122 | 27.36 | 15.77 | 0.000 |
| 123 | 24.17 | 13.71 | 16.00 |
| 124 | 15.31 | 12.40 | 4.000 |
| 125 | 13.09 | 11.26 | 13.00 |
| 126 | 21.94 | 11.54 | 2.000 |
| 127 | 25.25 | 10.61 | 0.000 |
| 128 | 25.62 | 08.27 | 0.000 |
| 129 | 28.55 | 10.09 | 0.000 |
| 130 | 29.91 | 12.23 | 0.000 |
| 131 | 27.87 | 14.00 | 0.000 |
| 132 | 27.75 | 16.03 | 1.000 |
| 133 | 31.26 | 15.05 | 0.000 |
| 134 | 25.84 | 18.03 | 3.000 |
| 135 | 28.44 | 14.25 | 0.000 |
| 136 | 30.64 | 10.94 | 0.000 |
| 137 | 31.20 | 15.43 | 0.000 |
| 138 | 26.97 | 15.69 | 0.000 |
| 139 | 29.19 | 17.28 | 0.000 |
| 140 | 22.72 | 15.47 | 4.000 |
| 141 | 21.04 | 08.90 | 0.000 |
| 142 | 22.14 | 09.10 | 0.000 |
| 143 | 15.69 | 12.36 | 6.000 |
| 144 | 18.43 | 12.56 | 1.000 |
| 145 | 28.44 | 11.46 | 1.000 |
| 146 | 22.57 | 16.42 | 10.00 |
| 147 | 23.41 | 14.97 | 1.000 |
| 148 | 23.91 | 13.55 | 0.000 |
| 149 | 26.97 | 10.98 | 0.000 |
| 150 | 28.90 | 12.81 | 0.000 |
| 151 | 31.33 | 12.89 | 0.000 |
| 152 | 30.83 | 16.33 | 0.000 |
| 153 | 23.81 | 12.36 | 24.00 |
| 154 | 25.78 | 09.93 | 0.000 |
| 155 | 28.84 | 07.36 | 0.000 |
| 156 | 30.21 | 11.46 | 0.000 |
| 157 | 31.64 | 12.23 | 0.000 |
| 158 | 32.61 | 15.94 | 0.000 |

Table B.3., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 159 | 33.14 | 18.34 | 0.000 |
| 160 | 30.70 | 18.65 | 0.000 |
| 161 | 28.90 | 18.56 | 6.000 |
| 162 | 34.02 | 16.42 | 13.00 |
| 163 | 35.34 | 17.02 | 0.000 |
| 164 | 36.21 | 16.20 | 0.000 |
| 165 | 38.02 | 17.63 | 0.000 |
| 166 | 38.80 | 19.56 | 0.000 |
| 167 | 36.65 | 19.60 | 0.000 |
| 168 | 34.99 | 18.30 | 11.00 |
| 169 | 29.43 | 16.76 | 0.000 |
| 170 | 27.75 | 15.77 | 2.000 |
| 171 | 31.83 | 16.59 | 0.000 |
| 172 | 33.54 | 17.90 | 0.000 |
| 173 | 34.50 | 18.38 | 0.000 |
| 174 | 33.47 | 16.54 | 0.000 |
| 175 | 32.35 | 17.06 | 11.00 |
| 176 | 29.67 | 15.77 | 0.000 |
| 177 | 31.96 | 13.63 | 18.00 |
| 178 | 34.08 | 15.82 | 0.000 |
| 179 | 34.57 | 16.89 | 2.000 |
| 180 | 24.32 | 17.37 | 07.00 |
| 181 | 25.25 | 14.34 | 0.000 |
| 182 | 29.61 | 11.38 | 0.000 |
| 183 | 31.90 | 15.82 | 11.00 |
| 184 | 31.45 | 19.65 | 0.000 |
| 185 | 29.08 | 15.99 | 26.00 |
| 186 | 34.64 | 18.38 | 1.000 |
| 187 | 34.22 | 17.68 | 0.000 |
| 188 | 31.64 | 19.06 | 0.000 |
| 189 | 32.94 | 16.80 | 6.000 |
| 190 | 33.20 | 19.78 | 1.000 |
| 191 | 36.36 | 22.62 | 0.000 |
| 192 | 35.41 | 23.26 | 1.000 |
| 193 | 23.86 | 12.11 | 6.000 |
| 194 | 26.70 | 09.46 | 0.000 |
| 195 | 26.92 | 10.82 | 0.000 |
| 196 | 34.57 | 15.26 | 0.000 |
| 197 | 35.70 | 19.24 | 0.000 |
| 198 | 26.81 | 20.52 | 15.00 |
| 199 | 38.02 | 19.56 | 0.000 |
| 200 | 36.36 | 21.75 | 0.000 |
| 201 | 35.41 | 22.23 | 0.000 |
| 202 | 34.43 | 20.85 | 0.000 |
| 203 | 33.88 | 20.52 | 0.000 |
| 204 | 36.36 | 21.46 | 0.000 |

Table B.3., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 205 | 37.10 | 20.29 | 0.000 |
| 206 | 36.73 | 19.19 | 0.000 |
| 207 | 36.21 | 19.74 | 0.000 |
| 208 | 36.28 | 18.83 | 0.000 |
| 209 | 36.95 | 20.94 | 0.000 |
| 210 | 37.25 | 19.60 | 0.000 |
| 211 | 38.41 | 20.71 | 0.000 |
| 212 | 39.77 | 19.42 | 0.000 |
| 213 | 42.39 | 23.51 | 0.000 |
| 214 | 40.09 | 22.38 | 0.000 |
| 215 | 32.48 | 19.83 | 13.00 |
| 216 | 31.07 | 18.38 | 0.000 |
| 217 | 32.15 | 15.77 | 0.000 |
| 218 | 37.71 | 20.06 | 0.000 |
| 219 | 36.88 | 19.92 | 1.000 |
| 220 | 29.97 | 19.88 | 0.000 |
| 221 | 27.70 | 15.94 | 0.000 |
| 222 | 32.28 | 11.79 | 0.000 |
| 223 | 36.28 | 18.25 | 18.00 |
| 224 | 26.97 | 19.47 | 49.00 |
| 225 | 26.92 | 18.65 | 0.000 |
| 226 | 32.87 | 18.07 | 0.000 |
| 227 | 36.80 | 21.56 | 0.000 |
| 228 | 33.07 | 18.56 | 0.000 |
| 229 | 34.08 | 16.37 | 07.00 |
| 230 | 26.75 | 17.02 | 6.000 |
| 231 | 34.22 | 16.76 | 0.000 |
| 232 | 38.72 | 18.30 | 0.000 |
| 233 | 40.43 | 25.31 | 0.000 |
| 234 | 25.57 | 11.99 | 6.000 |
| 235 | 21.23 | 11.54 | 6.000 |
| 236 | 18.65 | 12.97 | 3.000 |
| 237 | 31.20 | 16.46 | 1.000 |
| 238 | 21.89 | 14.76 | 0.000 |
| 239 | 24.73 | 13.34 | 0.000 |
| 240 | 28.84 | 12.03 | 0.000 |
| 241 | 29.25 | 13.88 | 0.000 |
| 242 | 26.10 | 15.60 | 0.000 |
| 243 | 26.43 | 12.72 | 0.000 |
| 244 | 35.85 | 12.68 | 0.000 |
| 245 | 30.21 | 12.77 | 0.000 |
| 246 | 35.77 | 15.64 | 0.000 |
| 247 | 34.15 | 18.43 | 0.000 |
| 248 | 25.52 | 17.50 | 1.000 |
| 249 | 28.21 | 15.14 | 1.000 |
| 250 | 29.85 | 12.97 | 0.000 |

Table B.3., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 251 | 26.26 | 13.30 | 0.000 |
| 252 | 32.61 | 13.09 | 2.000 |
| 253 | 28.90 | 09.85 | 0.000 |
| 254 | 25.68 | 11.50 | 0.000 |
| 255 | 25.10 | 12.03 | 0.000 |
| 256 | 32.09 | 13.96 | 0.000 |
| 257 | 33.20 | 18.21 | 0.000 |
| 258 | 29.25 | 15.22 | 0.000 |
| 259 | 27.59 | 13.18 | 0.000 |
| 260 | 25.25 | 13.30 | 0.000 |
| 261 | 25.57 | 11.42 | 0.000 |
| 262 | 25.73 | 09.57 | 0.000 |
| 263 | 27.75 | 6.778 | 0.000 |
| 264 | 22.62 | 5.608 | 0.000 |
| 265 | 26.37 | 3.170 | 0.000 |
| 266 | 31.96 | 6.700 | 0.000 |
| 267 | 33.20 | 09.50 | 0.000 |
| 268 | 30.15 | 08.82 | 0.000 |
| 269 | 32.22 | 11.70 | 0.000 |
| 270 | 30.83 | 14.63 | 6.000 |
| 271 | 25.94 | 09.42 | 0.000 |
| 272 | 24.12 | 5.803 | 0.000 |
| 273 | 27.14 | 4.754 | 0.000 |
| 274 | 33.00 | 07.75 | 0.000 |
| 275 | 18.92 | 3.517 | 0.000 |
| 276 | 23.11 | -0.017 | 0.000 |
| 277 | 34.36 | 6.544 | 0.000 |
| 278 | 21.70 | 4.328 | 0.000 |
| 279 | 24.53 | 1.325 | 0.000 |
| 280 | 20.80 | 1.517 | 0.000 |
| 281 | 25.41 | 4.367 | 0.000 |
| 282 | 15.64 | 4.483 | 0.000 |
| 283 | 5.880 | 1.171 | 0.000 |
| 284 | 16.76 | 2.169 | 0.000 |
| 285 | 25.10 | -01.62 | 0.000 |
| 286 | 25.46 | 3.286 | 0.000 |
| 287 | 24.37 | 07.32 | 2.000 |
| 288 | 11.91 | 6.309 | 5.000 |
| 289 | 17.68 | 0.788 | 2.000 |
| 290 | 23.61 | -03.28 | 0.000 |
| 291 | 17.94 | 2.131 | 0.000 |
| 292 | 13.88 | 2.631 | 0.000 |
| 293 | 14.51 | -01.66 | 0.000 |
| 294 | 20.62 | -03.62 | 0.000 |
| 295 | 18.38 | 3.517 | 0.000 |
| 296 | 12.52 | 1.478 | 0.000 |

Table B.3., continued.

| Julian date | Maximum | Minimum | Precip. |
|---|---|---|---|
| 297 | 13.67 | 2.285 | 0.000 |
| 298 | 11.87 | 2.208 | 08.00 |
| 299 | 20.06 | 2.631 | 0.000 |
| 300 | 19.28 | 1.171 | 0.000 |
| 301 | 26.75 | -0.477 | 0.000 |
| 302 | 29.31 | 3.903 | 0.000 |
| 303 | 23.97 | 3.517 | 6.000 |
| 304 | 23.41 | 11.06 | 0.000 |
| 305 | 20.15 | 10.41 | 0.000 |

PREDICTING LOSSES IN GRAIN SORGHUM [SORGHUM BICOLOR (L.) MOENCH] CAUSED BY FREEZES DURING GRAINFILL

by

GREGORY J. ROGGENKAMP

B. S. Kansas State University 1985

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AN ABSTRACT OF A MASTER'S THESIS

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Kansas State University
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ABSTRACT

Modelers and crop yield forecasters would like to better predict and comprehend impacts suffered from natural agronomic disasters such as early fall freezes on grain sorghum [Sorghum bicolor (L.) Moench]. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] in 1986 and 1987 and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] in 1987. Percent maximum seed weight and test weight were measured with the variables bloom date, hybrid, and location-year and regressed on growing degree-days (GDD) from anthesis to physiological maturity. Percent maximum seed weight and test weight were best described by quadratic polynomials. Combined over all hybrids and location-years: Percent maximum seed wt. = $-43.0 + 0.276\text{GDD} - 0.0001332\text{GDD}^2$. This regression accounted for 95% of the variability in seed weight and predicted maximum seed weight at 1040 GDD. With a combined regression, cumulative GDD accounted for 86% of the total variability for test weight and predicted maximum test weight to be reached at 912 GDD. It appears that maximum test weight is reached before maximum seed weight. Studies were then conducted to evaluate the effects of

foliar application of paraquat ( 1,1'-dimethyl-4,4'-bipyridinium ion) to simulate effects of freezing on seed weight and test weight. The desiccation method gave much higher percent maximum seed weights and test weights, especially in the early phase of grainfill (200 to 500 GDD), compared to the head cut method. Apparently, translocation of materials from the culm contributed to these increased seed weights and test weights.